10 Food, Soil, and Pest Management

CORE CASE STUDY Is Organic Agriculture the Answer?

We face the critical challenges of increasing food production without causing serious environmental harm. Each day, there are about 225,000 more mouths to feed and by 2050 there will probably be 2.5 billion more people to feed. This increase alone is more than twice China's current population and eight times the current U.S. population.

Sustainability experts call for us to develop and phase in more sustainable agricultural systems over the next few decades. One component of more sustainable agriculture is **organic agriculture**, in which crops and animals are grown with little or no use of synthetic pesticides, synthetic fertilizers, genetically engineered seeds, synthetic growth regulators, or feed additives. Organic agriculture is compared with conventional agriculture in Figure 10-1.

Although certified organic farming has grown rapidly since 1990, it is used on less than 1% of the world's cropland and only 0.1% of U.S. cropland. But in many European countries, 6–18% of the cropland is devoted to organic farming. Since 1969, when their oil supply from the Soviet Union was cut off, Cubans have grown most of their food using organic agriculture. The government has established centers where organisms used for biological pest control are produced, and it encourages people to grow organic food in urban gardens. About 30% of the vegetables in Havana, Cuba, are grown organically on land in the city.

Research conducted over 2 decades indicates that organic farming has a number of environmental advantages over conventional farming. On the other hand, organic farming requires more human labor. Another drawback is that most organically grown food costs 10–75% more than conventionally produced food (depending on the items), primarily because organic farming is more labor intensive. But if we included the costs of the harmful environmental impacts of food production in food prices, organic food would be cheaper than food produced by industrialized agriculture. In this chapter, we look at different ways to produce food, the environmental effects of food production, and how to produce food more sustainably.

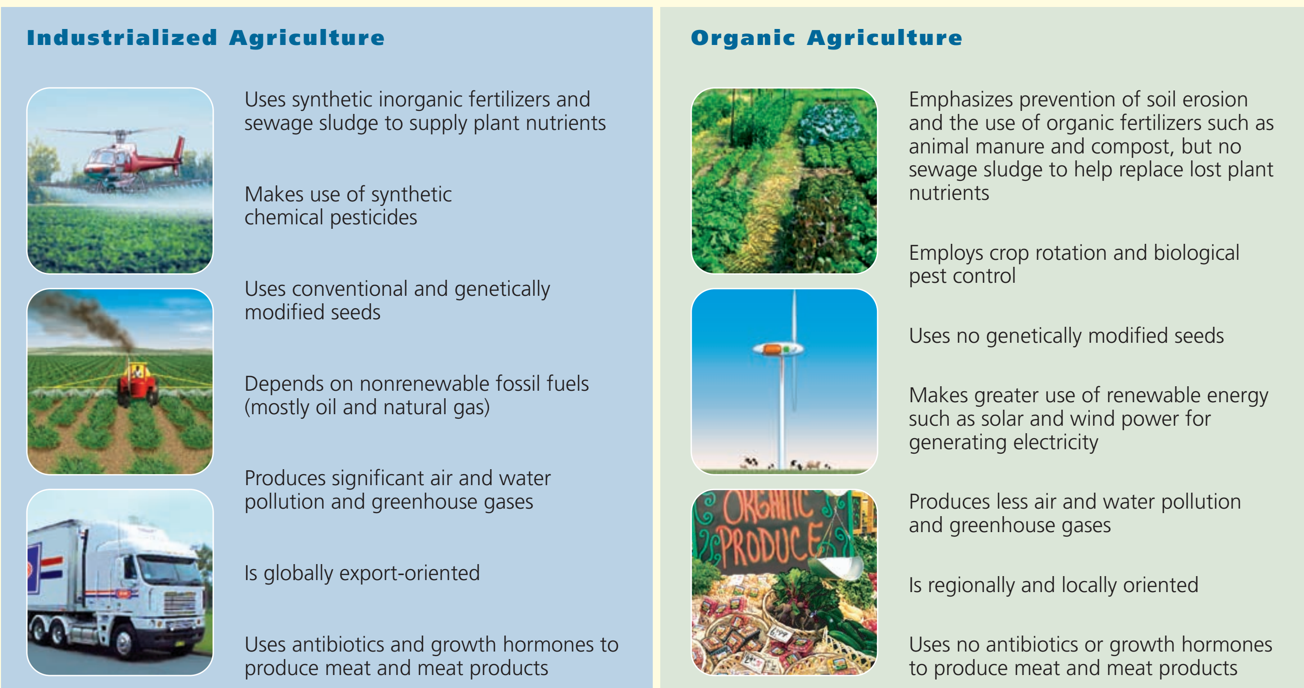

Figure 10-1 Comparison of conventional industrialized agriculture and organic agriculture. In the United States, a label of *100 percent organic* means that a product is raised only by organic methods and contains all organic ingredients. Products labeled *organic* must contain at least 95% organic ingredients. And products labeled *made with organic ingredients* must contain at least 70% organic ingredients but cannot display the USDA Organic seal on their packages.

Key Questions and Concepts

10-1 What is food security and why is it difficult to attain?

CONCEPT 10-1A Many of the poor have health problems from not getting enough food, while many people in affluent countries suffer health problems from eating too much.

CONCEPT 10-1B The greatest obstacles to providing enough food for everyone are poverty, political upheaval, corruption, war, and the harmful environmental effects of food production.

10-2 How is food produced?

CONCEPT 10-2 We have used high-input industrialized agriculture and lower-input traditional methods to greatly increase supplies of food.

10-3 What environmental problems arise from food production?

CONCEPT 10-3 Future food production may be limited by soil erosion and degradation, desertification, water and air pollution, climate change from greenhouse gas emissions, and loss of biodiversity.

10-4 How can we protect crops from pests more sustainably?

CONCEPT 10-4 We can sharply cut pesticide use without decreasing crop yields by using a mix of cultivation techniques, biological pest controls, and small amounts of selected chemical pesticides as a last resort (integrated pest management).

10-5 How can we improve food security?

CONCEPT 10-5 We can improve food security by creating programs to reduce poverty and chronic malnutrition, relying more on locally grown food, and cutting food waste.

10-6 How can we produce food more sustainably?

CONCEPT 10-6 More sustainable food production involves decreasing topsoil erosion, reducing overgrazing and overfishing, irrigating more efficiently, using integrated pest management, promoting agrobiodiversity, and providing government subsidies only for more sustainable agriculture, fishing, and aquaculture.

Note: Supplements 2 (p. S3), 3 (p. S6), 4 (p. S14), 6 (p. S26), and 7 (p. S32) can be used with this chapter.

There are two spiritual dangers in not owning a farm. One is the danger of supposing that breakfast comes from the grocery, and the other that heat comes from the furnace.

ALDO LEOPOLD

10-1 What Is Food Security and Why Is It Difficult to Attain?

CONCEPT 10-1A **Many of the poor have health problems from not getting enough food, while many people in affluent countries suffer health problems from eating too much.**

CONCEPT 10-1B **The greatest obstacles to providing enough food for everyone are poverty, political upheaval, corruption, war, and the harmful environmental effects of food production.**

Many People Have Health Problems from Not Getting Enough to Eat

Today, we produce more than enough food to meet the basic nutritional needs of every person on the earth, and thus to provide them with **food security**. But even with this food surplus, one of every six people in developing countries is not getting enough to eat. These people face **food insecurity**—living with chronic hunger and poor nutrition, which threatens their ability to lead healthy and productive lives (**Concept 10-1A**).

Most agricultural experts agree that *the root cause of food insecurity is poverty*, which prevents poor people from growing or buying enough food. Other obstacles to food security are environmental degradation, political upheaval, war (Figure 10-2, p. 208), and corruption (**Concept 10-1B**). In addition, according to a 2009 study by climate scientist David Battisti and food scientist

Harmut Schwartzbach/Peter Arnold, Inc.

Figure 10-2 *War and hunger:* starving children collecting ants to eat in famine-stricken Sudan, Africa, where a civil war has been going on since 1983.

Rosamond Naylor, there is a higher than 90% chance that by the end of this century, half of the world's population will face serious food shortages because of a rapidly warming climate.

To maintain good health and resist disease, individuals need fairly large amounts of *macronutrients* (such as carbohydrates, proteins, and fats, see Figures 8, 9, and 12, pp. S29–S30, in Supplement 6), and smaller amounts of *micronutrients*—vitamins (such as A, C, and E) and minerals (such as iron, iodine, and calcium).

People who cannot grow or buy enough food to meet their basic energy needs suffer from **chronic undernutrition**, or **hunger** (**Concept 10-1A**). (See Figure 11, p. S12, in Supplement 3 for a global map of chronic hunger and malnutrition.) Most of the world's chronically undernourished children live in low-income developing countries. Many suffer from mental retardation or stunted growth or die prematurely from infectious diseases such as measles and diarrhea, which rarely kill children in developed countries.

Many of the world's poor can afford only to live on a low-protein, high-carbohydrate, vegetarian diet consisting mainly of grains such as wheat, rice, or corn. They often suffer from **chronic malnutrition**—deficiencies of protein and other key nutrients. This weakens them, makes them more vulnerable to disease, and hinders the normal physical and mental development of children.

According to the U.N. Food and Agriculture Organization (FAO), there were an estimated 925 million chronically undernourished or malnourished people (Figure 1-13, p. 17) in 2007—more than 3 times the entire U.S. population.

CONNECTIONS

Corn, Ethanol, and Hunger

Since 2007, prices for corn, rice, wheat, and other basic foodstuffs have risen sharply. This was caused by a number of factors, including the diversion of large quantities of corn, primarily in the United States, to make ethanol fuel for cars. Much of this corn would have been used as food for livestock and people. The resulting rise in food prices has led to food riots and social unrest in 30 countries, including Thailand, Pakistan, Egypt, Haiti, and Mexico. In a 2007 study, University of Minnesota economists Ford Runge and Benjamin Senauer estimated that rising food prices and a sharp drop in international food aid could lead to an increase in the number of hungry and malnourished people from 925 million to 1.2 billion, which is roughly equal to the current population of China.

In 2005, the FAO estimated that each year, nearly 6 million children die prematurely from chronic undernutrition and malnutrition and increased susceptibility to normally nonfatal infectious diseases (such as measles and diarrhea) because of their weakened condition (**Concept 10-1A**). This means that each day, an average of 16,400 children die prematurely from these mostly poverty-related causes. How many children died from such causes during your lunch hour?

According to the World Health Organization (WHO), one of every three people suffers from a deficiency of one or more vitamins and minerals, usually *vitamin A*, *iron*, and *iodine*. Most of these people live in developing countries. Some 250,000–500,000 children younger than age 6 go blind each year from a lack of vitamin A, and within a year, more than half of them die.

Having too little *iron*—a component of the hemoglobin that transports oxygen in the blood—causes *anemia*. It results in fatigue, makes infection more likely, and increases a woman's chances of dying from hemorrhage in childbirth. According to the WHO, one of every five people in the world—mostly women and children in tropical developing countries—suffers from iron deficiency.

Elemental *iodine* is essential for proper functioning of the thyroid gland, which produces hormones that control the body's rate of metabolism. Iodine is found in seafood and in crops grown in iodine-rich soils. Chronic lack of iodine can cause stunted growth, mental retardation, and goiter—a swollen thyroid gland that can lead to deafness (Figure 10-3). Almost one-third of the world's people do not get enough iodine in their food and water. According to the United Nations, some 600 million people (almost twice the current U.S. population)—most of them in rural areas of south and southeast Asia—suffer from goiter. And 26 million children suffer irreversible brain damage with an IQ loss of

Figure 10-3 Woman with goiter in Bangladesh. A diet insufficient in iodine can cause this enlargement of the thyroid gland. Adding traces of iodine to salt has largely eliminated this problem in developed countries but iodine deficiency is a serious problem in many developing countries.

10–15 points each year from lack of iodine. According to the FAO and the WHO, eliminating this serious health problem would cost the equivalent of only 2–3 cents per year for every person in the world.

Correcting dietary deficiencies of key vitamins and minerals is not a glamorous problem that attracts widespread publicity or donors. But according to the World Bank, "Probably no other technology offers as large an opportunity to improve lives . . . at such low cost and in such a short time."

Many People Have Health Problems from Eating Too Much

Overnutrition occurs when food energy intake exceeds energy use and causes excess body fat. Too many calories, too little exercise, or both can cause overnutrition. People who are underfed and underweight and those who are overfed and overweight face similar health problems: *lower life expectancy, greater susceptibility to disease and illness, and lower productivity and life quality* (**Concept 10-1A**).

We live in a world where 925 million people have health problems because they do not get enough to eat and about 1.6 billion people face health problems from eating too much. In other words, for every four of the world's hungry people, there are nearly seven people who are overweight.

In 2007, the Centers for Disease Control and Prevention (CDC) found that about 66% of American adults are overweight and 34% are obese (up from 15% in 1980)—the highest overnutrition rate of all developed countries. Today in America, four of the top ten causes of death are diseases related to diet—heart disease, stroke, Type 2 diabetes, and some forms of cancer. The roughly $58 billion that Americans spend each year trying to lose weight (according to the research firm MarketData Enterprises) is more than twice the $24 billion per year that the United Nations estimates is needed to eliminate undernutrition and malnutrition in the world.

10-2 How Is Food Produced?

▶ **CONCEPT 10-2 We have used high-input industrialized agriculture and lower-input traditional methods to greatly increase supplies of food.**

Food Production Has Increased Dramatically

About 10,000 years ago, humans began to shift from hunting and gathering their food to growing it. They gradually developed agriculture, with which they grew edible plants in nutrient-rich topsoil and raised animals for food and labor. Today three systems supply most of our food. *Croplands* produce mostly grains. *Rangelands, pastures*, and *feedlots* produce meat. And *fisheries* and *aquaculture* (fish farming) provide us with seafood.

These three systems depend on a small number of plant and animal species. Of the estimated 50,000 plant species that people can eat, only 14 of them supply an estimated 90% of the world's food calories. Just three grain crops— *rice*, *wheat*, and *corn*—provide about 47% of the calories that people consume. A small number of animals also provide most of the world's meat and seafood.

Since 1960, there has been a staggering increase in global food production from all three of the major food production systems (**Concept 10-2**). GOOD NEWS

This occurred because of technological advances such as increased use of tractors and farm machinery and high-tech fishing equipment. Other technological developments include inorganic chemical fertilizers, high-volume irrigation, pesticides, high-yield grain varieties, and raising large numbers of livestock, poultry, fish, and shellfish in factory-like conditions.

Industrialized Crop Production Relies on High-Input Monocultures

Agriculture used to grow crops can be divided roughly into two types: industrialized agriculture and subsistence agriculture. **Industrialized agriculture**, or **high-input agriculture**, uses heavy equipment and large amounts of financial capital, fossil fuel, water, commercial inorganic fertilizers, and pesticides to produce single crops, or *monocultures*, (Figure 7-14, p. 134). The major goal of industrialized agriculture is to steadily increase each crop's *yield*—the amount of food produced per unit of land. Industrialized agriculture on about one-fourth of the world's cropland, mostly in developed countries, produces about 80% of the world's food (**Concept 10-2**).

Industrialized agriculture involves several important shifts:

- From relying on energy from sunlight, human muscle power, and draft animals to supplementing such energy with cheap energy from fossil fuels (primarily oil and natural gas).
- From producing a diversity of crops and farm animals (polycultures) to producing a few types of crops and animals (monocultures).
- From producing food mostly for local and regional consumption to producing food for global consumption.
- From relying on supply and demand in the marketplace to using government subsidies and policies to help manipulate supply and demand and keep food prices artificially low.

Plantation agriculture is a form of industrialized agriculture used primarily in tropical developing countries. It involves growing *cash crops* such as bananas, soybeans (mostly to feed livestock), sugarcane (to produce sugar and ethanol fuel), coffee, palm oil (used as a cooking oil and to produce biodiesel fuel), and vegetables. Crops are grown on large monoculture plantations, mostly for export to developed countries. Producing such monoculture crops in the tropics increases yields but decreases biodiversity when tropical forests are cleared or burned (Figure 9-12, p. 187) to make way for crop plantations.

Modern industrialized agriculture produces large amounts of food at reasonable prices. But is it sustainable? A growing number of analysts say it is not because it violates the three **principles of sustainability** by relying more on fossil fuels than on sunlight, reducing natural and crop biodiversity, and neglecting the conservation and recycling of nutrients in topsoil (Science Focus, right). What makes industrialized agriculture even more unsustainable is that our economic systems do not include the harmful environmental costs of food production in the market prices of food. This makes food prices much lower than the real costs of producing food, which we eventually pay in other ways.

Traditional Agriculture Often Relies on Low-Input Polycultures

Some 2.7 billion people (40% of the world's people) in developing countries practice *traditional agriculture*. It provides about one-fifth of the world's food crops on about three-fourths of its cultivated land.

There are two main types of traditional agriculture. **Traditional subsistence agriculture** supplements energy from the sun (for photosynthesis) with the labor of humans and draft animals to produce enough crops for a farm family's survival, with little left over to sell or store as a reserve for hard times. In **traditional intensive agriculture**, farmers increase their inputs of human and draft-animal labor, animal manure for fertilizer, and water to obtain higher crop yields. If the weather cooperates, they produce enough food to feed their families and have some left to sell for income.

Some traditional farmers focus on cultivating a single crop, but many grow several crops on the same plot simultaneously, a practice known as **polyculture**. Such crop diversity—an example of implementing the biodiversity **principle of sustainability** (see back cover)—reduces the chance of losing most or all of the year's food supply to pests, bad weather, and other misfortunes.

In parts of South America and Africa, some traditional farmers grow as many as 20 different crops together on small cleared plots in tropical forests. The crops rely on sunshine for their growth rather than on petroleum-based fertilizers. They mature at different times, provide food throughout the year, reduce the input of human labor, and keep the soil covered to reduce erosion from wind and water. Polyculture lessens needs for fertilizer and water, because root systems at different depths in the soil capture nutrients and moisture efficiently. Insecticides and herbicides are rarely needed because multiple habitats are created for natural predators of crop-eating insects, and weeds have trouble competing with the multitude of crop plants.

Recent research shows that, on average, such low-input polyculture produces higher yields than does high-input monoculture. For example, a 2001 study by ecologists Peter Reich and David Tilman found that carefully controlled polyculture plots with 16 different species of plants consistently out-produced plots with 9, 4, or only 1 type of plant species. Therefore, some analysts argue for greatly increased use of polyculture to produce food more sustainably.

SCIENCE FOCUS

Soil Is the Base of Life on Land

Soil is a complex mixture of eroded rock, mineral nutrients, decaying organic matter, water, air, and billions of living organisms, most of them microscopic decomposers. Soil formation begins when bedrock is slowly broken down into fragments and particles by physical, chemical, and biological processes, called *weathering*. Figure 10-A shows profiles of different-aged soils.

Soil, the base of life on land, is a key component of the earth's natural capital. It supplies most of the nutrients needed for plant growth (Figure 3-5, p. 43), purifies and stores water, and helps to control the earth's climate by removing carbon dioxide from the atmosphere and storing it as carbon compounds.

Most soils that have developed over a long period of time, called *mature soils*, contain horizontal layers, or *horizons*, (Figure 10-A), each with a distinct texture and composition. The numbers and types of horizons vary with different types of soils, but most mature soils have at least three of the possible horizons. Think of them as the top three floors in the geological building of life underneath your feet.

The roots of most plants and the majority of a soil's organic matter are concentrated in a soil's two upper layers, the *O horizon* of leaf litter and the *A horizon* of topsoil. In most mature soils, these two layers teem with bacteria, fungi, earthworms, and small insects, all interacting in complex ways. Bacteria and other decomposer microorganisms, found by the billions in every handful of topsoil, break down some of the soil's complex organic compounds. The result is a porous mixture of the partially decomposed bodies of dead plants and animals, called *humus*, and inorganic materials such as clay, silt, and sand. Soil moisture carrying dissolved nutrients is drawn up by the roots of plants and transported through stems and into leaves as part of the earth's chemical cycling processes.

The *B horizon* (*subsoil*) and the *C horizon* (*parent material*) contain most of a soil's inorganic matter, mostly broken-down rock consisting of varying mixtures of sand, silt, clay, and gravel. Much of it is transported by water from the A horizon (Figure 10-A). The C horizon lies on a base of parent material, which is often *bedrock*.

The spaces, or *pores,* between the solid organic and inorganic particles in the upper and lower soil layers contain varying amounts of air (mostly nitrogen and oxygen gas) and water. Plant roots use the oxygen for cellular respiration. As long as the O and A horizons are anchored by vegetation, the soil layers as a whole act as a sponge, storing water and releasing it in a nourishing trickle.

Some 15–20 centimeters (6–8 inches) of *topsoil* is all that stands between much of the world and mass starvation. Although topsoil is a renewable resource, it is renewed very slowly, which means it can be depleted. Just 1 centimeter (0.4 inch) of topsoil can take hundreds of years to form, but it can be washed or blown away in a matter of weeks or months when people plow grassland or clear a forest and leave its topsoil unprotected.

There are no technological substitutes for fertile and uncontaminated topsoil. Without topsoil, there would be no food and no life on the land. Thus, reducing and preventing soil erosion should be the most fundamental components of more sustainable agriculture.

Yet, for a long time, human activities have accelerated natural soil erosion and contaminated soils with excess salts, pesticides, and other chemicals that can reduce food production and biodiversity and threaten human health. We discuss the erosion and degradation of soil and solutions to these problems later in this chapter.

Critical Thinking

How does soil contribute to each of the four components of biodiversity described in Figure 4-2, p. 61?

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One very important advantage of polyculture is that it is less likely to degrade topsoil than industrialized agriculture is. The same can be said for organic agriculture (**Core Case Study**). All types of crop production depend on having fertile topsoil (Science Focus, p. 211).

CORE CASE STUDY

RESEARCH FRONTIER

Investigating the design and benefits of polyculture. See **www.cengage.com/biology/miller**.

CENGAGENOW™ Compare soil profiles from grassland, desert, and three types of forests at CengageNOW™.

A Closer Look at Industrialized Crop Production

Farmers can produce more food by farming more land or by getting higher yields from existing cropland. Since 1950, about 88% of the increase in global food production has come from using high-input industrialized agriculture (Figure 10-1, left) to increase yields in a process called the **green revolution**.

A green revolution involves three steps. *First,* develop and plant monocultures of selectively bred or genetically engineered high-yield varieties of key crops such as rice, wheat, and corn. *Second,* produce high yields by using large inputs of inorganic fertilizers, pesticides, and water. *Third,* increase the number of crops grown per year on a plot of land through *multiple cropping*. Between 1950 and 1970, this high-input approach dramatically increased crop yields in most developed countries, especially the United States (Case Study, at right) in what was called the *first green revolution*.

A *second green revolution* has been taking place since 1967. Fast-growing dwarf varieties of rice and wheat, specially bred for tropical and subtropical climates, have been introduced into India and China and several developing countries in Latin America such as Brazil (Case Study, p. 213). Producing more food on less land has helped to protect some biodiversity by preserving large areas of forests, grasslands, wetlands, and easily eroded mountain terrain that might be used for farming.

Between 1950 and 1996, mostly because of the two green revolutions, world grain production tripled (Figure 10-4, left). Per capita food production increased by 31% between 1961 and 1985, but since then it has generally declined (Figure 10-4, right).

CASE STUDY

Industrialized Food Production in the United States

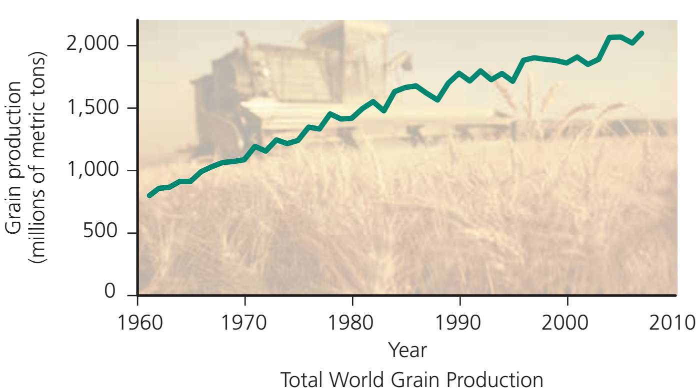
In the United States, industrialized farming has evolved into *agribusiness*, as a small number of giant multinational corporations increasingly control the growing, processing, distribution, and sale of food in U.S. and global markets.

In total annual sales, agriculture is bigger than the country's automotive, steel, and housing industries combined. The entire agricultural system (from farm to grocery store) employs more people than any other industry. Still, U.S. farms use industrialized agriculture to produce about 17% of the world's grain with only 3 of every 1,000 of the world's farm workers.

Since 1950, U.S. industrialized agriculture has more than doubled the yields of key crops such as wheat, corn, and soybeans without cultivating more land. Such yield increases have kept large areas of U.S. forests, grasslands, and wetlands from being converted to farmland.

GOOD NEWS

As a result of this system, Americans spend an average of less than 10% of their household income on food. But this is misleading because the huge government (taxpayer) agricultural subsidies and the high and harmful environmental costs of industrialized agricul-



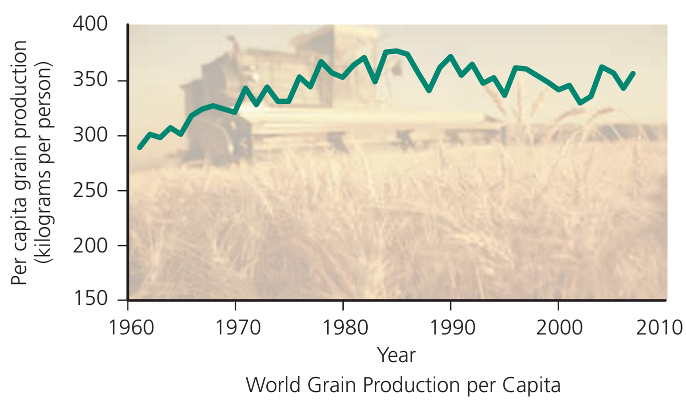


Figure 10-4 *Global outlook:* total worldwide grain production of wheat, corn, and rice (left), and per capita grain production (right), 1961–2007. In order, the world's three largest grain-producing countries are China, the United States, and India. **Question**: Why do you think grain production per capita has grown less consistently than total grain production? (Data from U.S. Department of Agriculture, Worldwatch Institute, U.N. Food and Agriculture Organization, and Earth Policy Institute)

ture are not included in the market prices of food. In other words, the prices of food in the United States are artificially low.

■ CASE STUDY
Brazil: The World's Emerging Food Superpower

Brazil, with ample sun and freshwater and more available arable (farmable) land than any other country, is on its way to becoming the next global breadbasket. One factor in this significant growth in food production is the Brazilian government's agricultural research corporation, EMBRAPA, which is now the world's largest agricultural research agency.

The country's agricultural scientists figured out how to modify soil and seeds to produce high crop yields on its humid, sun-drenched *cerrado*, a tropical savanna region that makes up about one-fifth of Brazil's huge land area. Because of favorable weather, farmers in this region routinely grow two crops a year (and three with irrigation) compared to one crop a year in the breadbasket of the midwestern United States. And they produce food without the huge government farm subsidies provided in the United States and Europe.

The main problem delaying Brazil's emergence as the world's number one food producer and exporter is a lack of roads and shipping ports. Another problem is that the Cerrado area is one of the world's biodiversity hotspots (Figure 9-19, p. 196). Thus, clearing much of it to grow crops is a severe threat to its biodiversity.

Crossbreeding and Genetic Engineering Can Produce New Crop Varieties

For centuries, farmers and scientists have used *crossbreeding* through *artificial selection* to develop genetically improved varieties of crops and livestock animals. GOOD NEWS Such selective breeding in this first *gene revolution* has yielded amazing results. Ancient ears of corn were about the size of your little finger, and wild tomatoes were once the size of grapes.

Traditional crossbreeding is a slow process, typically taking 15 years or more to produce a commercially valuable new crop variety, and it can combine traits only from species that are genetically similar. Typically, resulting varieties remain useful for only 5–10 years before pests and diseases reduce their effectiveness. But important advances are still being made with this method.

Today, scientists are creating a second *gene revolution* by using *genetic engineering* to develop genetically improved strains of crops and livestock animals. It involves altering an organism's genetic material through adding, deleting, or changing segments of its DNA (Figure 11, p. S30, in Supplement 6) to produce desirable traits or to eliminate undesirable ones—a process that is also called *gene splicing*. It enables scientists to transfer genes between different species that would not interbreed in nature. The resulting organisms are called *genetically modified organisms (GMOs)*. Figure 10-5 (p. 214) outlines the steps involved in developing a genetically modified plant. Compared to traditional crossbreeding, developing a new crop variety through gene splicing takes about half as long, usually costs less, and allows for the insertion of genes from almost any other organism into crop cells.

Ready or not, much of the world is entering the *age of genetic engineering*. At least three-fourths of the food products on U.S. supermarket shelves contain some form of genetically engineered food, and the proportion is increasing rapidly. Bioengineers are developing, or plan to develop, new varieties of crops that are resistant to heat, cold, herbicides, insect pests, parasites, viral diseases, drought, and salty or acidic soil. They also hope to develop crop plants that can grow faster and survive with little or no irrigation and with less fertilizer and pesticides.

Many scientists believe that such innovations hold great promise for helping to improve global food security. Others warn that genetic engineering is not free of drawbacks, which we examine later in this chapter.

Meat Production Has Grown Steadily

Meat and meat products such as eggs and milk are good sources of high-quality protein. Between 1950 and 2008, world meat production increased more than fivefold. It is likely to more than double again by 2050 as affluence rises and middle-income people begin consuming more meat in rapidly developing countries such as China, which now leads the world in both meat production and consumption.

About half of the world's meat comes from livestock grazing on grass in unfenced rangelands and enclosed pastures. The other half is produced through an energy-intensive industrialized system in which animals are raised mostly in densely packed *feedlots* and *confined animal feeding operations* where they are fed grain or meal produced from fish. For example, large numbers of cattle are brought to feedlots where they are fattened up for about 4 months before slaughter. Most pigs and chickens in developed countries spend their lives in pens and cages, often in huge buildings where they eat mostly grain grown on cropland.

Fish and Shellfish Production Have Increased Dramatically

The world's third major food-producing system consists of fisheries and aquaculture. Industrial fishing fleets take most of the world's marine fish catch (Case

Study, p. 200). In 2006, 43% of the fish and shellfish consumed were produced through **aquaculture**—raising marine and freshwater fish in ponds and underwater cages instead of hunting and gathering them. This percentage is expected to grow steadily.

Figure 10-6 shows the effects of the global efforts to boost the seafood harvest through fishing and aquaculture (**Concept 10-2**). Since 1950, the world fish catch (marine and freshwater harvests, excluding aquaculture) has increased almost sevenfold. Aquacultural production in the same period increased over 40-fold.

China raises 70% of the world's farmed fish, mostly in inland ponds and rice fields. Globally, aquaculture is devoted mostly to raising herbivorous species—mainly carp in China and India, catfish in the United States, tilapia in several countries, and shellfish in several coastal countries. But the farming of carnivorous fish is growing rapidly, especially in developed countries. As a result, nearly one-third of global catch of wild fish is converted to fish meal and fish oil and fed to farmed carnivorous fish, cattle, and pigs.

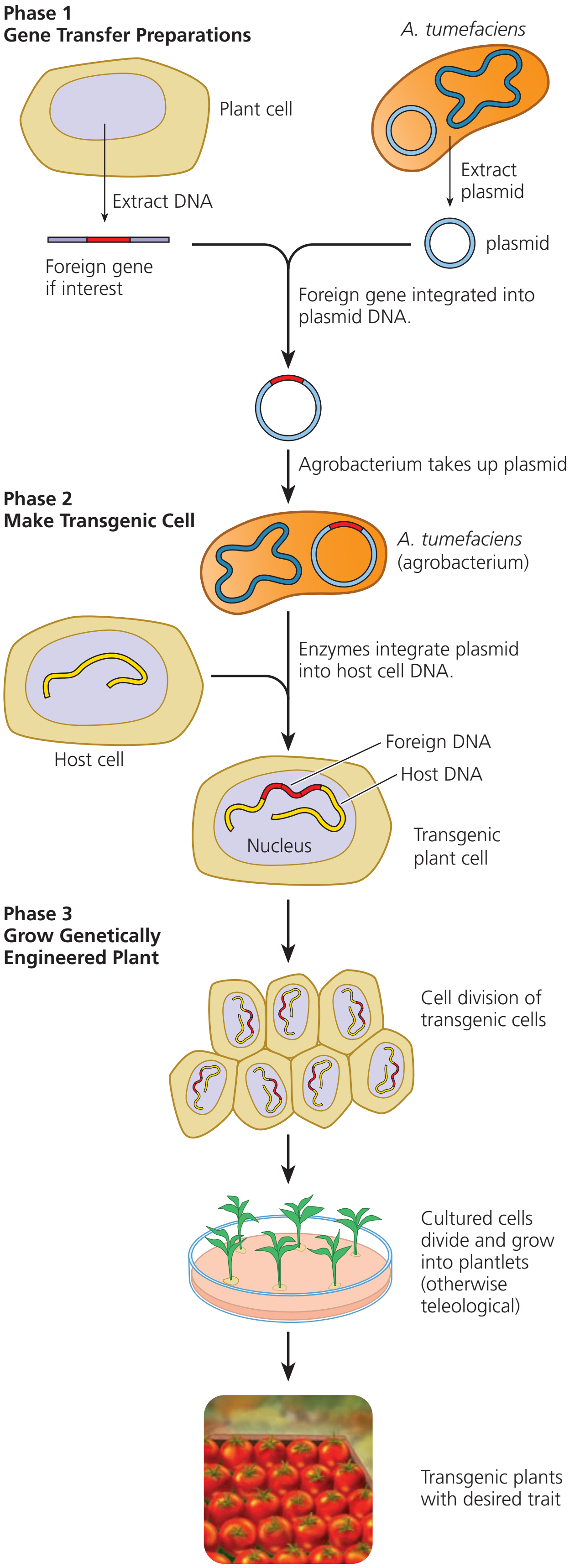
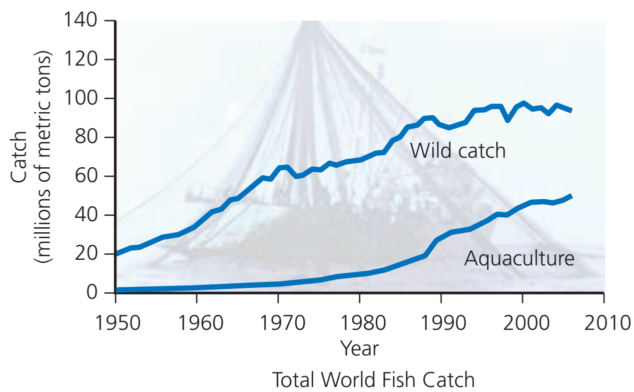


Figure 10-5 *Genetic engineering:* steps in genetically modifying a plant. **Question**: How does this process change the nature of evolution by natural selection?



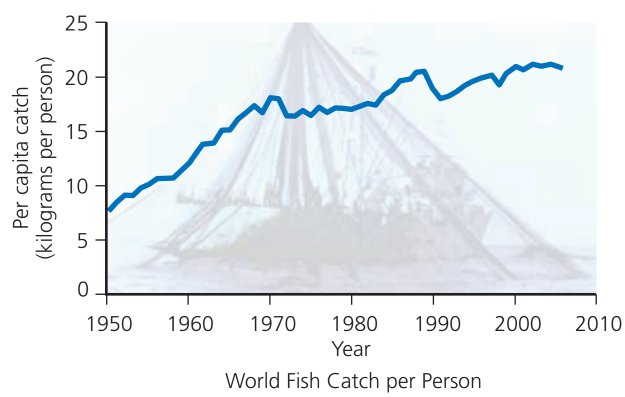


Figure 10-6 World fish catch, including both wild catch and aquaculture, 1950–2006. **Question**: What are two trends that you can see in these data? (Data from U.N. Food and Agriculture Organization, U.S. Census Bureau, and Worldwatch Institute)

10-3 What Environmental Problems Arise from Food Production?

> **CONCEPT 10-3** Future food production may be limited by soil erosion and degradation, desertification, water and air pollution, climate change from greenhouse gas emissions, and loss of biodiversity.

Producing Food Has Major Environmental Impacts

The good news is the spectacular increases in the world's food production since 1950. The bad news is the harmful environmental effects associated with such production increases. Figure 10-7 summarizes the harmful effects of modern agriculture on air, fertile soil, water, and biodiversity. According to many analysts, agriculture has a greater total harmful environmental impact than any human activity. Some scientists warn that these environmental effects may limit future food production and make it unsustainable (**Concept 10-3**). Here, we explore such effects in greater depth, starting with the problems of erosion and degradation of soils.

Topsoil Erosion Is a Serious Problem in Parts of the World

Soil erosion is the movement of soil components, especially surface litter and topsoil (Science Focus, p. 211), from one place to another by the actions of wind and water. Some soil erosion is natural, and some is caused

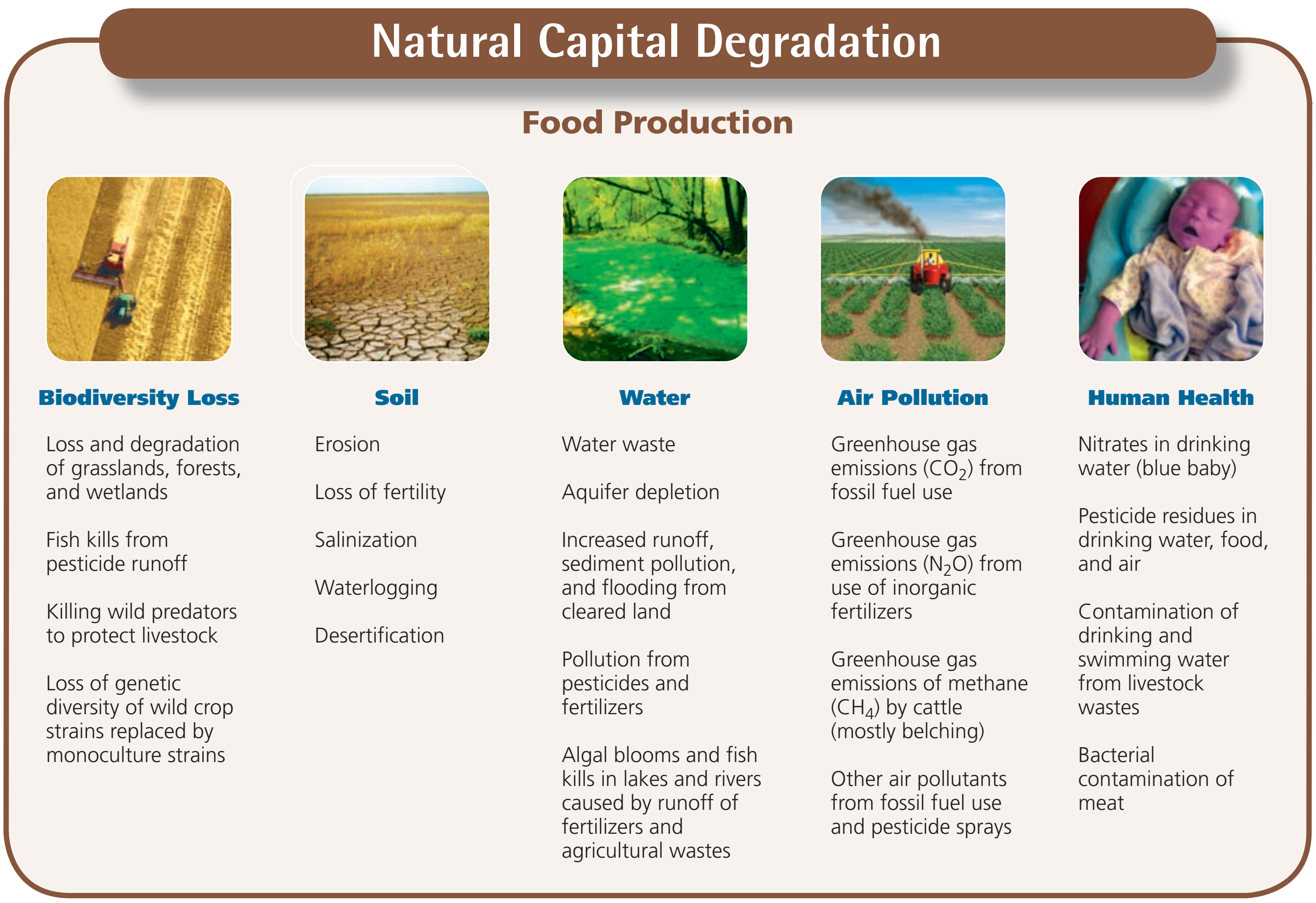


Figure 10-7 Natural capital degradation: major harmful environmental effects of food production (**Concept 10-3**). According to a 2008 study by the U.N. Food and Agriculture Organization (FAO), more than 20% of the world's cropland (65% in Africa) has been degraded to some degree by soil erosion, salt buildup, and chemical pollution. This threatens the food supply for about a quarter of the world's population who are trying to eke out a living on such degraded land. **Question**: Which item in each of these categories do you believe is the most harmful?

Figure 10-8 **Natural capital degradation:** severe gully erosion on cropland in Bolivia.

by human activities. In undisturbed, vegetated ecosystems, the roots of plants help to anchor the soil. The soil can then store water and release it in a nourishing trickle, and, usually, soil is not lost faster than it forms.

Flowing water, the largest cause of erosion, carries away particles of topsoil that have been loosened by rainfall. Severe erosion of this type leads to the formation of gullies (Figure 10-8). Wind loosens and blows topsoil particles away, especially in areas with a dry climate and relatively flat and exposed land. We lose natural capital in the form of fertile topsoil when we destroy soil-holding grasses through activities such as farming (Figure 7-14, p. 134), clear-cutting forests (Figure 9-9, p. 184), and overgrazing (Figure 9-16, left, p. 191).

Soil erosion has two major harmful effects. One is *loss of soil fertility* through depletion of plant nutrients in topsoil. The other is *water pollution* in nearby surface waters, where eroded soil ends up as sediment. This can kill fish and shellfish and clog irrigation ditches, boat channels, reservoirs, and lakes. Additional water pollution occurs when the eroded sediment contains residues of pesticides. In degrading soil and polluting water, we are altering the carbon, nitrogen, and phosphorus cycles by removing vital plant nutrients from the soil and adding excess plant nutrients to aquatic systems.

In 2008, the Chinese government estimated that one-third of its land suffers from serious soil erosion. And a joint survey by the U.N. Environment Programme (UNEP) and the World Resources Institute estimated that topsoil is eroding faster than it forms on about 38% of the world's cropland (Figure 10-9) and has cut crop production by about 17%. (See the Guest Essay on soil erosion by David Pimentel at CengageNOW.) However, in some cases the loss in crop yields in one area can be offset by an increased yield when eroded topsoil is deposited in another area.

Drought and Human Activities Are Degrading Drylands

In arid and semiarid parts of the world, the contribution to the world's food supply from livestock and crops is being threatened by **desertification**. It occurs when the productive potential of soil falls by 10% or more because of a combination of prolonged drought and human activities that reduce or degrade topsoil. The process can be *moderate* (a 10–25% drop in productivity), *severe* (a 25–50% drop), or *very severe* (a drop of more

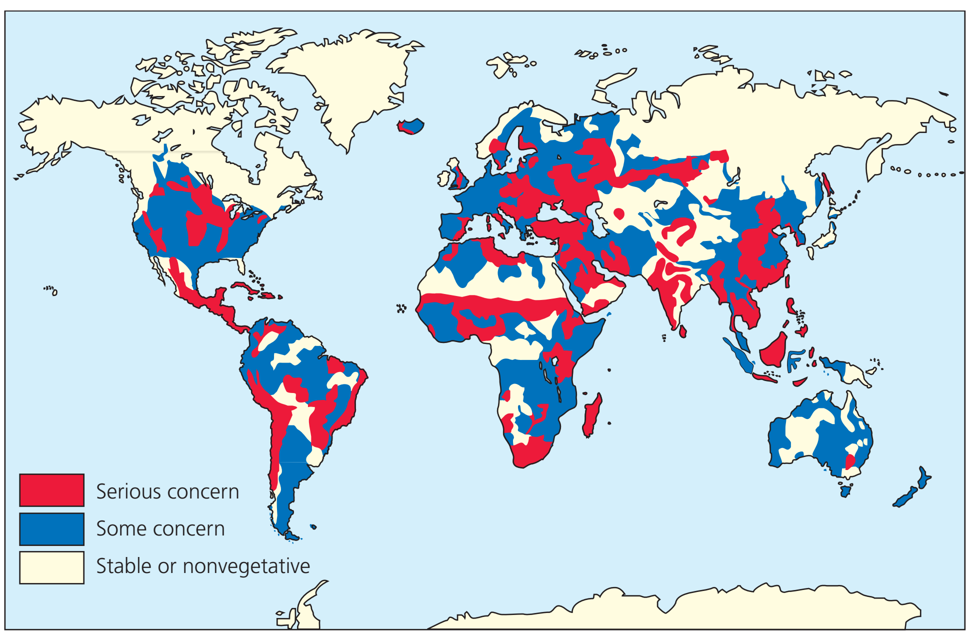


Figure 10-9 **Natural capital degradation:** global soil erosion. **Question**: Can you see any geographical pattern associated with this problem? (Data from U.N. Environment Programme and the World Resources Institute).

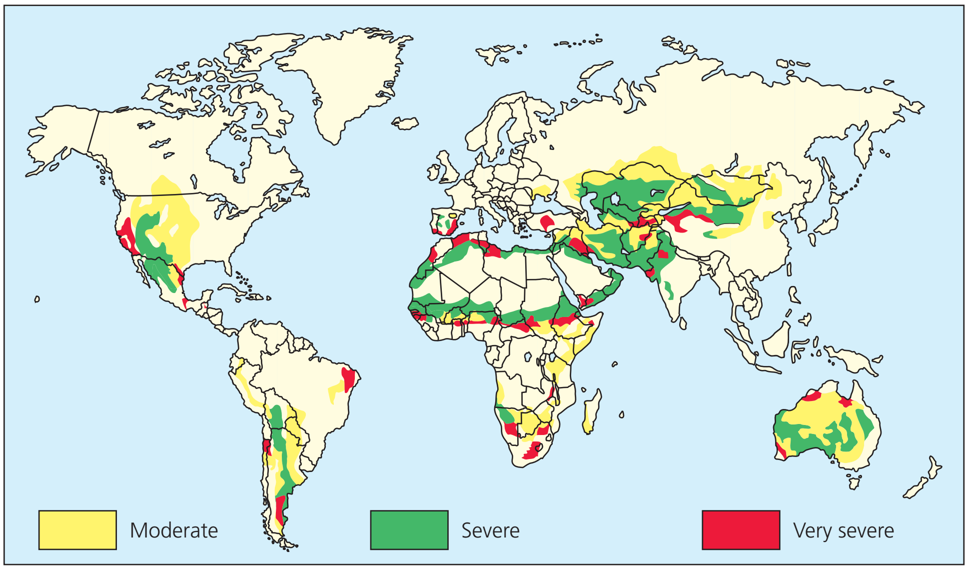


Figure 10-10 **Natural capital degradation:** desertification of arid and semiarid lands. It is caused by a combination of prolonged drought and human activities that expose soil to erosion. **Question**: Can you see any geographical pattern associated with this problem? (Data from U.N. Environment Programme and Harold E. Drengue)

than 50%, usually resulting in huge gullies and sand dunes, see Figure 10-10). Only in extreme cases does desertification lead to what we call desert. In its 2007 report on the *Status of the World's Forests*, the FAO estimated that some 70% of world's drylands used for agriculture are degraded and threatened by desertification.

According to a 2007 study by the Intergovernmental Panel on Climate Change, projected climate change during this century (mostly the result of human activities) is expected to greatly increase severe and prolonged drought and, consequently, desertification in arid and semiarid parts of the world. This could result in sharp drops in food production (**Concept 10-3**), water shortages for 1–3 billion people, and huge numbers of environmental refugees.

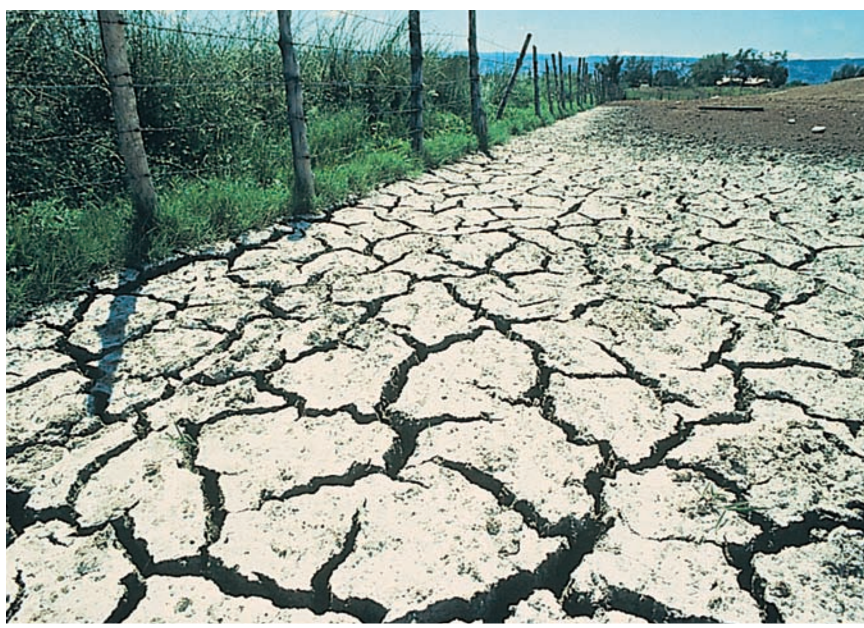
Excessive Irrigation Has Serious Consequences

Between 1950 and 2008, the world's area of irrigated cropland tripled, with most of the growth occurring from 1950 to 1978. Currently, about one-fifth of the world's cropland is irrigated. It produces about 45% of the world's food.

But irrigation has a downside. Most irrigation water is a dilute solution of various salts that are picked up as the water flows over or through soil and rocks. Irrigation water that has not been absorbed into the soil evaporates, leaving behind a thin crust of dissolved salts in the topsoil.

Repeated annual applications of irrigation water in dry climates lead to the gradual accumulation of salts in the upper soil layers—a soil degradation process called **salinization**. It stunts crop growth, lowers crop yields, and can eventually kill plants and ruin the land (**Concept 10-3**). The United Nations estimates that severe salinization has reduced yields on at least one-tenth of the world's irrigated cropland, and the problem is getting worse. The most severe salinization occurs in Asia, especially in China, India, Egypt, Pakistan, and Iraq. Salinization affects almost one-fourth of irrigated cropland in the United States, especially in western states (Figure 10-11).

Another problem with irrigation is **waterlogging**, in which water accumulates underground and gradually raises the water table. Farmers often apply large amounts of irrigation water to leach salts deeper into the soil. Without adequate drainage, waterlogging occurs and saline water then surrounds the deep roots of plants, lowering their productivity and killing them after prolonged exposure. At least one-tenth of the world's irrigated land suffers from waterlogging, and the problem is getting worse (**Concept 10-3**).



U.S. Natural Resources Conservation Service

Figure 10-11 **Natural capital degradation:** Because of high evaporation, poor drainage, and severe salinization, white alkaline salts have displaced crops that once grew on this heavily irrigated land in the U.S. state of Colorado.

There May Be Limits to Expanding the Green Revolutions

Several factors have limited the success of the green revolutions to date and may limit them in the future. Without huge inputs of inorganic fertilizer, pesticides, and water, most green revolution crop varieties produce yields that are no higher (and are sometimes lower) than those from traditional strains. And these high-inputs cost too much for most subsistence farmers in developing countries.

Can we expand the green revolutions by irrigating more cropland? In 2006, the International Water Management Institute projected that between 2005 and 2050, water use for agriculture will have to increase by 80% to help provide food for an estimated 2.5 billion more people.

However, since 1978, the amount of irrigated land per person has been declining, and it is projected to fall much more between 2008 and 2050. One reason for this is that, since 1978, the world's population has grown faster than has use of irrigation. Other factors are depletion of underground water supplies (aquifers), wasteful use of irrigation water, soil salinization, and climate change, which is melting mountain glaciers that provide irrigation water for countries such as China and India. In addition, most of the world's farmers do not have enough money to irrigate their crops.

Is cultivating more land the answer? Clearing tropical forests and irrigating arid land could more than double the area of the world's cropland. But much of this is *marginal land* with poor soil fertility, steep slopes, or both. Cultivating marginal land is usually expensive, is unlikely to be sustainable, and reduces wildlife habitats and biodiversity. In addition, during this century, fertile croplands in many coastal areas are likely to be flooded by rising sea levels resulting from climate change.

Industrialized Food Production Requires Huge Inputs of Energy

The industrialization of agriculture has been made possible by the availability of energy, mostly from nonrenewable oil. It is used to run farm machinery, irrigate crops, and produce pesticides (mostly from petrochemicals produced when oil is refined) and commercial inorganic fertilizers. Fossil fuels are also used to process food and transport it long distances within and between countries. Putting food on the table consumes about 19% of the fossil fuel energy used in the United States each year—more than any other sector of the economy except cars.

In 1940, it took about 1 unit of fossil fuel energy to put 2.3 units of food energy on the table in the United States. Today, when we consider the energy used to grow, store, process, package, transport, refrigerate, and cook all plant and animal food, *it takes about 10 units of nonrenewable fossil fuel energy are to put 1 unit of food energy on the table*. In the United States, food travels an average 2,400 kilometers (1,300 miles) from farm to plate. Some types of food take more energy to produce than others do. According to a 2002 study by the John Hopkins Bloomberg School of Public Health, it takes 35 units of energy to produce 1 unit of energy in grain-fed beef. And this does not include the additional energy used to process, transport, and cook the beef.

Using large ships to find, catch, and freeze ocean fish also requires huge amounts of energy. According to a 2005 study by ecological economist Peter Tyedmers and his colleagues, this large-scale hunting and gathering operation by the world's fishing fleets uses about 12.5 times as much energy as the fish provide for the people who eat them.

Bottom line: industrialized food production and consumption, overall, results in a large *net energy loss*.

THINKING ABOUT
Food and Oil

What might happen to industrialized food production and to your lifestyle if oil prices rise sharply in the next 2 decades, as many analysts predict? How would you reduce this risk for yourself and your loved ones?

There Is Controversy over Genetically Engineered Foods

Despite its promise, controversy has arisen over the use of *genetically modified* (*GM*) *food* (Figure 10-5) and other products of genetic engineering. Its producers and investors see GM food as a potentially sustainable way to solve world hunger problems and improve human health. But some critics consider it potentially dangerous "Frankenfood." Figure 10-12 summarizes projected advantages and disadvantages of this new technology.

Critics recognize the potential benefits of GM crops. But they warn that we know too little about the long-term potential harm to human health and ecosystems from the widespread use of such crops. They point out that genetic engineering mixes genes from widely differing species, which has never occurred in nature or even in selective breeding. They warn that if GM organisms released into the environment cause some unintended harmful genetic and ecological effects, as some scientists expect, they cannot be recalled.

For example, genes in plant pollen from genetically engineered crops can spread among nonengineered species. The new strains can then form hybrids with wild crop varieties, which could reduce the natural genetic biodiversity of wild strains. This could reduce the gene pool needed to crossbreed new crop varieties and to develop new genetically engineered varieties. This also threatens the production of certified organic crops (**Core Case Study**), which must be grown in the absence of GM crop genes. Critics call for more controlled field experiments, long-term testing to evaluate the risks, and stricter regulation of this rapidly growing technology.

CORE CASE STUDY

Trade-Offs

Genetically Modified Crops and Foods

Projected Advantages	Projected Disadvantages
Need less fertilizer	Irreversible and unpredictable genetic and ecological effects
Need less water	Harmful toxins in food from possible plant cell mutations
More resistant to insects, disease, frost, and drought	New allergens in food
Grow faster	Lower nutrition
Can grow in slightly salty soils	Increase in pesticide-resistant insects, herbicide-resistant weeds, and plant diseases
May need less pesticides	Can harm beneficial insects
Tolerate higher levels of herbicides	Lower genetic diversity
Higher yields	
Less spoilage	

Figure 10-12 Projected advantages and disadvantages of genetically modified crops and foods. **Questions**: Which two advantages and which two disadvantages do you think are the most important? Why?

Another issue related to GM food arises from court decisions granting seed companies patents (and thus exclusive ownership) of GM crop varieties. Companies with such patents have successfully sued some farmers who saved the seeds from their crops for use in the following year (an important component of agriculture for thousands of years) rather than buying a new batch of seeds. They have also successfully sued farmers to have them pay seed costs for crops that came up from GM seeds blown onto their land. Seed companies argue that they have spent large amounts of money developing these new varieties and that patents allow them to recoup their expenses and make profits.

Critics argue that such companies take genetic resources and traditional knowledge about crops developed over thousands of years for free, modify them slightly, and claim in court that they have invented these varieties that were based primarily on ancient varieties. Then they patent each type of seed, claim an exclusive right to it, and charge anyone for using it. Critics say that this will allow a few large seed companies to own and control the world's seed supply and thus its food supply.

THINKING ABOUT
Gene Patenting

Do you believe that companies should have the legal right to patent crop varieties and other forms of life? How could this benefit or harm you?

Food and Biofuel Production Systems Have Caused Major Losses of Biodiversity

Natural biodiversity and some ecological services are threatened when forests are cleared and grasslands are plowed up and replaced with croplands used to produce food or biofuels such as ethanol (**Concept 10-3**).

A related problem is the increasing loss of *agrobiodiversity*—the world's genetic variety of animals and plants used to provide food. Scientists estimate that since 1900, we have lost three-fourths of the genetic diversity of agricultural crops. For example, India once planted 30,000 varieties of rice. Now more than 75% of its rice production comes from only ten varieties and soon, almost all of its production may come from just one or two varieties. In the United States, about 97% of the food plant varieties that were available to farmers in the 1940s no longer exist, except perhaps in small amounts in seed banks and in the backyards of a few gardeners.

In other words, we are rapidly shrinking the world's genetic "library," which is critical for increasing food yields. In fact, we might soon need it more than ever to develop new plant and livestock varieties that can adapt to climate change. This failure to preserve agrobiodiversity is a serious violation of the biodiversity **principle of sustainability**.

Industrialized Meat Production Has Harmful Environmental Consequences

Proponents of industrialized meat production point out that producing meat by using feedlots and other confined animal production facilities increases meat production, reduces overgrazing, and yields higher profits. But environmental scientists point out that such systems use large amounts of energy (mostly fossil fuels) and water and produce huge amounts of animal waste that sometimes pollute surface water and groundwater and saturate the air with their odors.

In 2008, the FAO reported that overgrazing, soil compaction, and erosion by livestock have degraded one-fifth of the world's grasslands and pastures. The same report estimated that rangeland grazing and industrialized livestock production cause 55% of all soil erosion and sediment pollution, use 37% of the world's pesticides, and account for half of all antibiotic use and a third of the water pollution that results from excessive inputs of nitrogen and phosphorous.

CONNECTIONS

Corn, Ethanol, and Ocean Dead Zones

Huge amounts of inorganic fertilizers are used in the midwestern United States to produce corn for animal feed and for conversion to ethanol fuel. Much of this fertilizer runs off cropland, eventually goes into the Mississippi River, and ends up over-fertilizing coastal waters in the Gulf of Mexico, where the river flows into the ocean. Each year, this creates a "dead zone" often larger than the size of the U.S. state of Massachusetts. This oxygen-depleted zone threatens one-fifth of the nation's seafood yield. In other words, growing corn in the Midwest to fuel cars with ethanol and to produce protein-rich meat decreases aquatic biodiversity and the production of protein-rich seafood in the Gulf of Mexico.

Energy (mostly from oil) is also an essential ingredient in industrialized meat production. Using this energy pollutes the air and water and contributes to projected climate change. Livestock production generates almost one-fifth of the world's greenhouse gases—more than all cars, buses, and planes emit—according to the 2006 FAO study, *Livestock's Long Shadow*.

Cattle and dairy cows also release the powerful greenhouse gas methane, mostly through belching. This accounts for 16% of the global annual emissions of methane. According to the Center for Science in the Public Interest, the methane that cattle produce in the United States each year is equal to the greenhouse gas emissions of 33 million automobiles. A 2003 Swedish study found that raising beef cattle on grass results in 40% lower greenhouse gas emissions and uses 85% less energy than raising the cattle on grain crops.

Finally, according to the United States Department of Agriculture (USDA), the American meat industry produces about 130 times more animal waste than is produced by the country's human population. Globally, only about half of all manure is returned to the land as nutrient-rich fertilizer—a violation of the nutrient recycling **sustainability principle**. Much of the other half of this waste ends up polluting the air, water, and soil and producing foul odors.

Producing Fish through Aquaculture Can Harm Aquatic Ecosystems

Figure 10-13 lists the major advantages and disadvantages of aquaculture. Some analysts project that aquaculture could provide at least half of the world's seafood by 2025. Others warn that the harmful environmental effects of aquaculture could limit future production.

Trade-Offs

Aquaculture

Advantages	Disadvantages
High efficiency	Needs large inputs of land, feed, and water
High yield in small volume of water	Large waste output
Can reduce overharvesting of fisheries	Can destroy mangrove forests and estuaries
Low fuel use	Uses grain, fish meal, and fish oil to feed some species
High profits	Dense populations vulnerable to disease

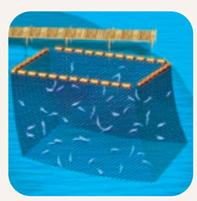


Figure 10-13 Advantages and disadvantages of *aquaculture.* **Questions**: Which single advantage and which single disadvantage do you think are the most important? Why?

One problem is that using fish meal and fish oil to feed farmed carnivorous fish can deplete populations of wild fish. It is also very inefficient. According to marine scientist John Volpe, it takes about 3 kilograms (6.6 pounds) of wild fish to produce 1 kilogram (2.2 pounds) of farmed salmon, and this ratio increases to 5 to 1 for farmed cod and 20 to 1 for farmed tuna.

Another problem is that fish raised on fish meal or fish oil can be contaminated with long-lived toxins such as PCBs found on ocean bottoms. In 2003, samples from various U.S. grocery stores revealed that farmed salmon had 7 times more PCBs than wild salmon had and 4 times more than those found in feedlot beef. A 2004 study found that farmed salmon also had levels of toxic dioxin 11 times higher than those of wild-caught salmon. Aquaculture producers contend that the concentrations of these chemicals are not high enough to threaten human health.

Fish farms also produce large amounts of wastes. Along with pesticides and antibiotics used in aquaculture operations, these wastes pollute aquatic ecosystems. This threatens aquatic biodiversity and can make these systems undesirable for recreation and other uses.

HOW WOULD YOU VOTE?

Do the advantages of aquaculture outweigh its disadvantages? Cast your vote online at **www.cengage.com/biology/miller**.

Later in this chapter (Section 10-5), we consider some possible solutions to the environmental problems that result from food production and some ways to produce food more sustainably. But first, let us consider a special set of environmental problems and solutions related to protecting food supply systems from pests.

10-4 How Can We Protect Crops from Pests More Sustainably?

CONCEPT 10-4 We can sharply cut pesticide use without decreasing crop yields by using a mix of cultivation techniques, biological pest controls, and small amounts of selected chemical pesticides as a last resort (integrated pest management).

Nature Controls the Populations of Most Pests

A **pest** is any species that interferes with human welfare by competing with us for food, invading lawns and gardens, destroying building materials, spreading disease, invading ecosystems, or simply being a nuisance. Worldwide, only about 100 species of plants ("weeds"), animals (mostly insects), fungi, and microbes cause most of the damage to the crops we grow.

In natural ecosystems and many polyculture agroecosystems, *natural enemies* (predators, parasites, and disease organisms) control the populations of most potential pest species. For example, the world's 30,000 known species of spiders, including the wolf spider (Figure 10-14), kill far more insects every year than humans do by using chemicals.

When we clear forests and grasslands, plant monoculture crops, and douse fields with chemicals that kill pests, we upset many of these natural population checks and balances that help to implement the biodiversity **principle of sustainability** (see back cover). Then we must devise and pay for ways to protect our monoculture crops, tree plantations, lawns, and golf courses from insects and other pests that nature once largely controlled at no charge.

Peter J. Bryant/Biological Photo Service.

Figure 10-14 Natural capital: Spiders are important insect predators that are killed by some pesticides. Most spiders, including this ferocious-looking wolf spider, do not harm humans.

We Use Pesticides to Help Control Pest Populations

We have developed a variety of **pesticides**—chemicals used to kill or control populations of organisms that we consider undesirable such as insects, weeds, rats, and mice. We did not invent the use of chemicals to repel or kill other species. For nearly 225 million years, plants have been producing chemicals to ward off, deceive, or poison herbivores that feed on them. This battle produces a never-ending, ever-changing coevolutionary process: herbivores overcome various plant defenses through natural selection (**Concept 4-2B**, p. 63), then new plant defenses are favored by natural selection, and the process is repeated in this ongoing cycle of evolutionary punch and counterpunch.

Since 1950, pesticide use has increased more than 50-fold, and most of today's pesticides are 10–100 times more toxic than those used in the 1950s. About three-fourths of these chemicals are used in developed countries, but their use in developing countries is soaring.

Some pesticides, called *broad-spectrum agents,* are toxic to many pests, but also to beneficial species. Examples are chlorinated hydrocarbon compounds such as DDT and organophosphate compounds such as malathion and parathion. Others, called *selective*, or *narrow-spectrum*, *agents*, are effective against a narrowly defined group of organisms.

Pesticides vary in their *persistence*, the length of time they remain deadly in the environment. Some such as DDT and related compounds remain in the environment for years and can be biologically magnified in food chains and webs (Figure 8-15, p. 166). Others such as organophosphates are active for days or weeks and are not biologically magnified but can be highly toxic to humans. About one-fourth of the pesticides used in the United States are aimed at ridding houses, gardens, lawns, parks, playing fields, swimming pools, and golf courses of pests. According to the Environmental Protection Agency (EPA), the average lawn in the United States is doused with ten times more synthetic pesticides per unit of land area than what is put on U.S. cropland. In 1962, biologist Rachel Carson warned against relying on synthetic organic chemicals to kill insects and other species we regard as pests (see Individuals Matter, at right).

Modern Synthetic Pesticides Have Several Advantages—the Good News

Conventional chemical pesticides have advantages and disadvantages. Proponents contend that their benefits (Figure 10-15, left) outweigh their harmful effects (Figure 10-15, right). They point to the following benefits:

- *They save human lives.* Since 1945, DDT and other insecticides probably have prevented the premature deaths of at least 7 million people (some say as many as 500 million) from insect-transmitted diseases such as malaria (carried by the *Anopheles* mosquito), bubonic plague (carried by rat fleas), and typhus (carried by body lice and fleas).
- *They increase food supplies.* According to the FAO, 55% of the world's potential human food supply is lost to pests. Without pesticides, these losses would be worse and food prices would rise.
- *They increase profits for farmers.* Officials of pesticide companies estimate that every dollar spent on pesticides leads to an increase in U.S. crop yields worth approximately $4.
- *They work fast.* Pesticides control most pests quickly, have a long shelf life, and are easily shipped and applied. When genetic resistance (p. 64) occurs, farmers can use stronger doses or switch to other pesticides.
- *When used properly, the health risks of some pesticides are very low, relative to their benefits.* Pesticide industry scientists argue that when pesticides are used as directed, they pose no major risk to farm workers and consumers.

Trade-Offs

Conventional Chemical Pesticides

Advantages	Disadvantages
Save lives	Promote genetic resistance
Increase food supplies	Kill natural pest enemies
Profitable	Pollute the environment
Work fast	Can harm wildlife and people
Safe if used properly	Are expensive for farmers

Figure 10-15 Advantages and disadvantages of conventional chemical pesticides. **Questions**: Which single advantage and which single disadvantage do you think are the most important? Why?

INDIVIDUALS MATTER

Rachel Carson

Rachel Carson (Figure 10-B) began her professional career as a biologist for the Bureau of U.S. Fisheries (now called the U.S. Fish and Wildlife Service). In that capacity, she carried out research in oceanography and marine biology and wrote articles and books about the oceans and topics related to the environment.

In 1958, the commonly used pesticide DDT was sprayed to control mosquitoes near the home and private bird sanctuary of one of Carson's friends. After the spraying, her friend witnessed the agonizing deaths of several birds. She begged Carson to find someone to investigate the effects of pesticides on birds and other wildlife.

Carson decided to look into the issue herself and found very little independent research on the environmental effects of pesticides. As a well-trained scientist, she surveyed the scientific literature, became convinced that pesticides could harm wildlife and humans, and gathered information about the harmful effects of widespread use of pesticides.

In 1962, she published her findings in popular form in *Silent Spring*, a book whose title warned of the potential silencing of "robins, catbirds, doves, jays, wrens, and scores of other bird voices" because of their exposure to pesticides. Many scientists, politicians, and policy makers read *Silent Spring*, and the public embraced it.

Chemical manufacturers understandably saw the book as a serious threat to their booming pesticide business, and they mounted a campaign to discredit Carson. A parade of critical reviewers and industry scientists claimed that her book was full of inaccuracies, made selective use of research findings, and failed to give a balanced account of the benefits of pesticides.

Some critics even claimed that, as a woman, Carson was incapable of understanding such a highly scientific and technical subject. Others charged that she was just an hysterical woman and radical nature lover, who was trying to scare the public in an effort to sell books.

During these intense attacks, Carson was a single mother and the sole caretaker of an aged parent. She was also suffering from terminal breast cancer. Yet she strongly defended her research and countered her critics. She died in 1964—about 18 months after the publication of *Silent Spring*—without knowing that many historians would consider her work to be an important contribution to the modern environmental movement then emerging in the United States.

It has been correctly noted that Carson made some errors in *Silent Spring*. But critics concede that the threat to birds and ecosystems—one of Carson's main messages—was real and that most of her errors can be attributed to the primitive state of research on the topics she covered in her day. And her critics cannot dispute the fact that her wake-up call got the public and the scientific community focused on the potential threats from uncontrolled use of pesticides. This eventually led to the banning of many pesticides in the United States and other countries. Carson's pioneering work also led to much more scientific research on the potential hazards of pesticides and other chemicals.

Image not available due to copyright restrictions

- *Newer pest control methods are safer and more effective than many older ones.* Greater use is being made of chemicals derived originally from plants. They are safer to use and less damaging to the environment than are many older pesticides. Genetic engineering is also being used to develop pest-resistant crop strains and genetically altered crops that produce natural pesticides.

Modern Synthetic Pesticides Have Several Disadvantages—the Bad News

Opponents of widespread pesticide use believe that the harmful effects of these chemicals (Figure 10-15, right) outweigh their benefits (Figure 10-15, left). They cite several serious problems with the use of conventional pesticides.

- *They accelerate the development of genetic resistance to pesticides in pest organisms.* Insects breed rapidly, and within 5–10 years (much sooner in tropical areas) they can develop immunity to widely used pesticides through natural selection and then come back stronger than before. Since 1945, about 1,000 species of insects and rodents (mostly rats) and 550 types of weeds and plant diseases have developed genetic resistance to one or more pesticides. Because of genetic resistance, farmers can find themselves having to pay more and more for a pest control program that becomes less and less effective.
- *Some insecticides kill natural predators and parasites that help control the pest populations.* Of the 300 most destructive insect pests in the United States, 100 were once minor pests that became major pests after widespread use of insecticides wiped out many of their natural predators.
- *Pesticides do not stay put and can pollute the environment.* According to the USDA, 98–99.9% of the insecticides and more than 95% of the herbicides that are applied do not reach the target pests and

end up in the air, surface water, groundwater, bottom sediments, food, and nontarget organisms, including humans and wildlife.

- *Some pesticides harm wildlife.* According to the USDA and the U.S. Fish and Wildlife Service, each year, pesticides applied to cropland wipe out about 20% of U.S. honeybee colonies and damage another 15% (Case Study, p. 167). Each year, pesticides also kill more than 67 million birds and 6–14 million fish. According to a 2004 study by the Center for Biological Diversity, pesticides also menace one of every three endangered and threatened species in the United States.
- *Some pesticides threaten human health.* The WHO and UNEP estimate conservatively that, each year, pesticides seriously poison at least 3 million agricultural workers in developing countries and at least 300,000 people in the United States. They also cause 20,000–40,000 deaths per year, worldwide. Each year, more than 250,000 people in the United States become ill because of household pesticide use. Such pesticides are a major source of accidental poisonings and deaths of young children.

According to studies by the National Academy of Sciences, exposure to legally allowed pesticide residues in food causes 4,000–20,000 cases of cancer per year in the United States. Some scientists are concerned about possible genetic mutations, birth defects, nervous system and behavioral disorders, and effects on the immune and endocrine systems from long-term exposure to low levels of various pesticides. The pesticide industry disputes these claims, arguing that the exposures are not high enough to cause serious harm. (See more on this topic in Chapter 14 and in *The Habitable Planet*, Video 7, at **www.learner.org/resources/series209.html**.)

Children are much more susceptible than adults are to low levels of pesticides and other toxic chemicals, because on an amount-per-weight basis, they eat more food, drink more water, and breathe more air. They also put their fingers in their mouths more often and spend more time playing on grass, carpeting, and soil where pesticides can accumulate.

Figure 10-16 lists some ways in which you can reduce your exposure to pesticides.

Pesticide use has not reduced U.S. crop losses to pests, mostly because of genetic resistance and reduction of natural predators. When David Pimentel, an expert on insect ecology, evaluated data from more than 300 agricultural scientists and economists, he reached three major conclusions:

- *First,* although the use of synthetic pesticides has increased 33-fold since 1942, about 37% of the U.S. food supply is lost to pests today compared to 31% in the 1940s. Since 1942, losses attributed to insects almost doubled from 7% to 13%, despite a tenfold increase in the use of synthetic insecticides.

What Can You Do?

Reducing Exposure to Pesticides

- Grow some of your food using organic methods
- Buy organic food
- Wash and scrub all fresh fruits, vegetables, and wild foods you pick
- Eat less meat or no meat
- Trim the fat from meat

Figure 10-16 **Individuals matter:** you can reduce your exposure to pesticides. **Questions**: Which three of these actions do you think are the most important? Why?

- *Second,* estimated environmental, health, and social costs of pesticide use in the United States, according to the International Food Policy Research Institute, are $5–10 in damages for every dollar spent on pesticides.
- *Third,* alternative pest management practices could cut the use of chemical pesticides by half on 40 major U.S. crops without reducing crop yields (**Concept 10-4**). The pesticide industry disputes these findings.

HOW WOULD YOU VOTE? ✓

Do the advantages of using synthetic chemical pesticides outweigh their disadvantages? Cast your vote online at **www.cengage.com/biology/miller**.

Laws Can Help to Protect Us from the Harmful Effects of Pesticides

In the United States, three U.S. federal agencies, the EPA, the USDA, and the Food and Drug Administration (FDA), regulate the sale and use of pesticides under the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA), first passed in 1947 and amended in 1972. In 1996, Congress passed the Food Quality Protection Act, mostly because of growing scientific evidence and citizen pressure concerning the effects of small amounts of pesticides on children. This act requires the EPA to reduce the allowed levels of pesticide residues in food by a factor of 10 when there is inadequate information on the potentially harmful effects on children.

There is controversy over how well U.S. citizens are protected from the harmful effects of pesticides, with some scientists calling FIFRA the weakest and most poorly enforced U.S. environmental law. After more than 37 years, less than 10% of the 600 active (pest-

SCIENCE FOCUS

Ecological Surprises: The Law of Unintended Consequences

Malaria once infected nine of every ten people in North Borneo, now known as the eastern Malaysian state of Sabah. In 1955, the WHO began spraying the island with dieldrin (a DDT relative) to kill malaria-carrying mosquitoes. The program was so successful that the dreaded disease was nearly eliminated.

Then unexpected things began to happen. The dieldrin also killed other insects, including flies and cockroaches living in houses. The islanders were happy. Next, small insect-eating lizards that also lived in the houses died after gorging themselves on dieldrin-contaminated insects.

Cats began dying after feeding on the lizards. In the absence of cats, rats flourished and overran the villages. When the people became threatened by sylvatic plague carried by rat fleas, the WHO parachuted healthy cats onto the island to help control the rats. Operation Cat Drop worked.

But then the villagers' roofs began to fall in. The dieldrin had killed wasps and other insects that fed on a type of caterpillar that had either avoided or was not affected by the insecticide. With most of its predators eliminated, the caterpillar population exploded, munching its way through its favorite food: the leaves used to thatch roofs.

Ultimately, this episode ended well: both malaria and the unexpected effects of the spraying program were brought under control. Nevertheless, this chain of unintended and unforeseen events emphasizes the unpredictability of using insecticides. It reminds us that when we intervene in nature, we can never do just one thing, and we need to ask, "Now what will happen?"

Critical Thinking

Do you think the beneficial effects of spraying pesticides in Sabah to kill malaria-carrying mosquitoes outweighed the resulting unexpected harmful effects? Explain.

killing) ingredients in pesticide products have been evaluated by using tests for chronic health effects. And serious evaluation of the health effects of the 1,200 inactive ingredients used in pesticide products began only recently.

Between 1972 and 2009, the EPA used FIFRA to ban or severely restrict the use of 64 active pesticide ingredients, including DDT and most other chlorinated hydrocarbon insecticides. However, according to studies by the National Academy of Sciences, federal laws regulating pesticide use in the United States are inadequate and poorly enforced by the three agencies. One study by the National Academy of Sciences found that as much as 98% of the potential risk of developing cancer from pesticide residues on food grown in the United States would be eliminated if EPA standards were as strict for pre-1972 pesticides as they are for later ones.

CONNECTIONS

Pesticides and Organic Foods

CORE CASE STUDY

According to the Environmental Working Group (EWG), you could reduce your pesticide intake by up to 90% by eating only organic versions of 12 types of conventional foods that tend to have the highest pesticide residues. These foods, which EWG calls the "dirty dozen," are peaches, apples, bell peppers, celery, nectarines, cherries, strawberries, lettuce, imported grapes, spinach, pears, and potatoes. Pesticide proponents say the residue concentrations in foods treated with pesticides are too low to cause harm. But some scientists urge consumers to play it safe by using the precautionary principle and buying only organic versions of the dirty dozen foods.

There Are Alternatives to Pesticides

Many scientists believe we should greatly increase the use of biological, ecological, and other alternative methods for controlling pests and diseases that affect crops and human health (**Concept 10-4**). Here are some of these alternatives:

- *Fool the pest.* A variety of *cultivation practices* can be used to fake out pests. Examples include rotating the types of crops planted in a field each year, adjusting planting times so that major insect pests either starve or get eaten by their natural predators, and growing crops in areas where their major pests do not exist.
- *Provide homes for pest enemies.* Farmers can increase the use of polyculture, which uses plant diversity to reduce losses to pests. Homeowners can apply the biodiversity sustainability principle by planting yards with a variety of low-maintenance natural plants adapted to local climates.
- *Implant genetic resistance.* Use genetic engineering to speed up the development of pest- and disease-resistant crop strains (Figure 10-17, p. 226). But controversy persists over whether the projected advantages of using GM plants and foods outweigh their projected disadvantages (Figure 10-13, right).
- *Bring in natural enemies*. Use *biological control* by importing natural predators (Figures 10-14 and 10-18, p. 226), parasites, and disease-causing bacteria and viruses to help regulate pest populations. This approach is nontoxic to other species, minimizes genetic resistance, and is usually less costly than applying pesticides. However, biological control agents are often slower acting and more difficult to apply than conventional pesticides are, can sometimes multiply and become pests themselves, and must be protected from pesticides sprayed in nearby fields.
- *Use insect perfumes. Sex attractants* (called *pheromones*) can lure pests into traps or attract their natural predators into crop fields. Each of these chemicals

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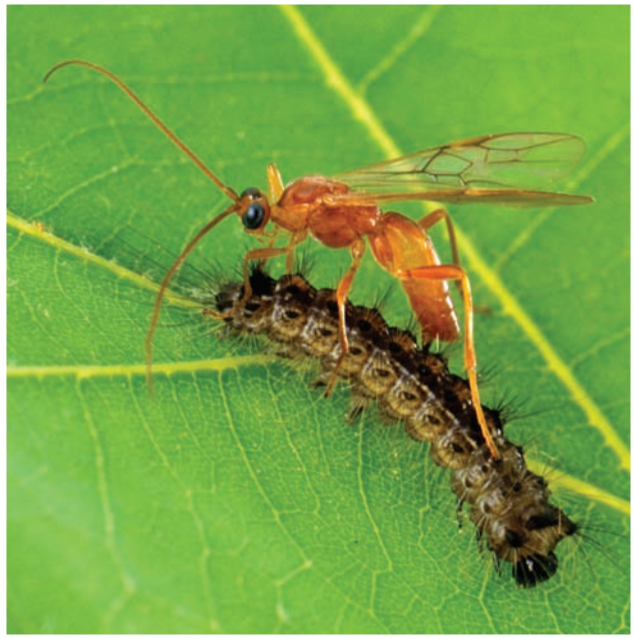


Scott Bauer/USDA Agricultural Research Service.

Figure 10-18 **Natural capital:** biological pest control. Wasp parasitizing a gypsy moth caterpillar.

attracts only one species, and they work in trace amounts, have little chance of causing genetic resistance, and are not harmful to nontarget species. However, it is costly and time-consuming to identify, isolate, and produce the specific sex attractant for each pest or predator.

- *Bring in the hormones.* Hormones are chemicals produced by animals to control developmental processes at different stages of life. Scientists have learned how to identify and use hormones that disrupt an insect's normal life cycle, thereby preventing it from reaching maturity and reproducing. Insect hormones have the same advantages as sex attractants. But they take weeks to kill an insect, often are ineffective with large infestations of insects, and sometimes break down before they can act. In addition, they must be applied at exactly the right time in the target insect's life cycle. They can sometimes affect the target's predators and other beneficial species and are difficult and costly to produce.

Integrated Pest Management Is a Component of More Sustainable Agriculture

Many pest control experts and farmers believe the best way to control crop pests is a carefully designed **integrated pest management** (**IPM**) program. In this more sustainable approach, each crop and its pests are evaluated as parts of an ecological system. Then farmers develop a carefully designed control program that uses a combination of cultivation, biological, and chemical tools and techniques (**Concept 10-4**).

The overall aim of IPM is to reduce crop damage to an economically tolerable level. Each year, crops are moved from field to field to disrupt pest infestations, and fields are monitored carefully. When an economically damaging level of pests is reached, farmers first use biological methods (natural predators, parasites, and disease organisms) and cultivation controls (such as rotating crops, altering planting time, and using large machines to vacuum up harmful bugs). They apply small amounts of insecticides—mostly based on those naturally produced by plants—only as a last resort and in the smallest amounts possible. Broad-spectrum, long-lived pesticides are not used, and different chemicals are used alternately to slow the development of genetic resistance and to avoid killing predators of pest species.

In 1986, the Indonesian government banned 57 of the 66 pesticides used on rice and phased out pesticide subsidies over a 2-year period. It also launched a nationwide education program to help farmers switch to IPM. The results were dramatic: Between 1987 and 1992, pesticide use dropped by 65%, rice production rose by 15%, and more than 250,000 farmers were trained in IPM techniques. (For more information and animations see *The Habitable Planet*, Video 7, at **www.learner.org/resources/series209.html**.) Sweden and Denmark have used IPM to cut their pesticide use by more than half. Cuba, which uses organic farming to grow its crops, makes extensive use of IPM. In Brazil, IPM has reduced pesticide use on soybeans by as much as 90%.

According to a 2003 study by the U.S. National Academy of Sciences, these and other experiences show

that a well-designed IPM program can reduce pesticide use and pest control costs by 50–65%, without reducing crop yields and food quality. IPM can also reduce inputs of fertilizer and irrigation water, and slow the development of genetic resistance, because pests are assaulted less often and with lower doses of pesticides. IPM is an important form of *pollution prevention* that reduces risks to wildlife and human health and applies the biodiversity **principle of sustainability**.

Despite its promise, IPM—like any other form of pest control—has some disadvantages. It requires expert knowledge about each pest situation and takes more time than does using conventional pesticides. Methods developed for a crop in one area might not apply to areas with even slightly different growing conditions. Initial costs may be higher, although long-term costs typically are lower than those of using conventional pesticides. Widespread use of IPM is hindered in the United States and a number of other countries by government subsidies for using conventional chemical pesticides, opposition by pesticide manufacturers, and a shortage of IPM experts. **GREEN CAREER:** Integrated pest management

HOW WOULD YOU VOTE?

Should governments heavily subsidize a switch to integrated pest management? Cast your vote online at **www.cengage.com/biology/miller**.

Several U.N. agencies and the World Bank have joined together to establish an IPM facility. Its goal is to promote the global use of IPM by disseminating information and establishing networks among researchers, farmers, and agricultural extension agents involved in IPM.

GOOD NEWS

10-5 How Can We Improve Food Security?

CONCEPT 10-5 We can improve food security by creating programs to reduce poverty and chronic malnutrition, relying more on locally grown food, and cutting food waste.

Use Government Policies to Improve Food Production and Security

Agriculture is a financially risky business. Whether farmers have a good or bad year depends on factors over which they have little control: weather, crop prices, crop pests and diseases, loan interest rates, and global markets.

Governments use two main approaches to influence food production:

- *Control prices.* Use price controls to keep food prices artificially low. This makes consumers happy but makes it harder for farmers to make a living.
- *Provide subsidies.* Give farmers price supports, tax breaks, and other subsidies to keep them in business and to encourage them to increase food production. According to the United Nations, subsidies and tax breaks provided by governments in developed countries average $533,000 a minute and account for about 31% of global farm income. Farmers in developing countries cannot compete in the global marketplace with the artificially low prices of subsidized crops in developed countries. Some analysts call for phasing out such subsidies. For example, in 1984, New Zealand ended farm subsidies. After the shock wore off, innovation took over and production of some foods such as milk quadrupled. Brazil (Case Study, p. 213) has also ended most of its farm subsidies. Other analysts call for replacing traditional subsidies for farmers with subsidies that promote more sustainable forms of agriculture.

Studies show that government subsidies to fishing fleets can promote overfishing and the subsequent reduction of aquatic biodiversity. For example, governments give the highly destructive bottom trawling industry (Figure 9-21, right, p. 199) about $150 million in subsidies a year, which is the main reason they can stay in business. Many analysts call for replacing those environmentally harmful (perverse) subsidies with payments that promote more sustainable fishing and aquaculture.

HOW WOULD YOU VOTE?

Should governments phase out subsidies for conventional industrialized agriculture and fishing and phase in subsidies for more sustainable agriculture and fishing? Cast your vote online at **www.cengage.com/biology/miller**.

To improve food security, some analysts urge governments to establish special programs focused on saving children from the harmful health effects of poverty. Studies by the United Nations Children's Fund

(UNICEF) indicate that one-half to two-thirds of nutrition-related childhood deaths could be prevented at an average annual cost of $5–10 per child with the following measures:

- Immunizing children against childhood diseases such as measles
- Encouraging breast-feeding (except for mothers with AIDS)
- Preventing dehydration from diarrhea by giving infants a mixture of sugar and salt in a glass of water
- Preventing blindness by giving children a vitamin A capsule twice a year at a cost of about 75¢ per child. Other options are fortifying common foods with vitamin A and other micronutrients at an annual cost of about 10¢ per child.
- Providing family planning services to help mothers space births at least 2 years apart
- Increasing education for women, with emphasis on nutrition, drinking water sterilization, contraception, and childcare

10-6 How Can We Produce Food More Sustainably?

▶ **CONCEPT 10-6 More sustainable food production involves decreasing topsoil erosion, reducing overgrazing and overfishing, irrigating more efficiently, using integrated pest management, promoting agrobiodiversity, and providing government subsidies only for more sustainable agriculture, fishing, and aquaculture.**

Reduce Soil Erosion

Using land to produce food requires fertile topsoil (Science Focus, p. 211). And it takes hundreds of years for fertile topsoil to form. Thus, sharply reducing soil erosion is the single most important component of more sustainable agriculture.

Soil conservation involves using a variety of ways to reduce soil erosion and restore soil fertility, mostly by keeping the soil covered with vegetation. Figure 10-19 shows some of the methods farmers have used to reduce soil erosion (**Concept 10-6**). For example, *terracing* is a way to grow food on steep slopes without depleting topsoil. It is done by converting steeply sloped land into a series of broad, nearly level terraces that run across the land's contours (Figure 10-19a). This retains water for crops at each level and reduces soil erosion by controlling runoff.

GOOD NEWS

On ground with a significant slope, *contour planting* (Figures 10-19b) can be used to reduce soil erosion. It involves plowing and planting crops in rows across the slope of the land rather than up and down. Each row acts as a small dam to help hold topsoil and to slow water runoff.

Strip cropping (Figure 10-19b) involves planting alternating strips of a row crop (such as corn or cotton) and another crop that completely covers the soil, called a *cover crop* (such as alfalfa, clover, rye, or a grass–legume mixture). The cover crop traps topsoil that erodes from the row crop and catches and reduces water runoff. When one crop is harvested the other strip is left to catch and reduce water runoff. Other ways to reduce erosion are to leave crop residues on the land after the crops are harvested or to plant cover crops immediately after harvest to help protect and hold the topsoil.

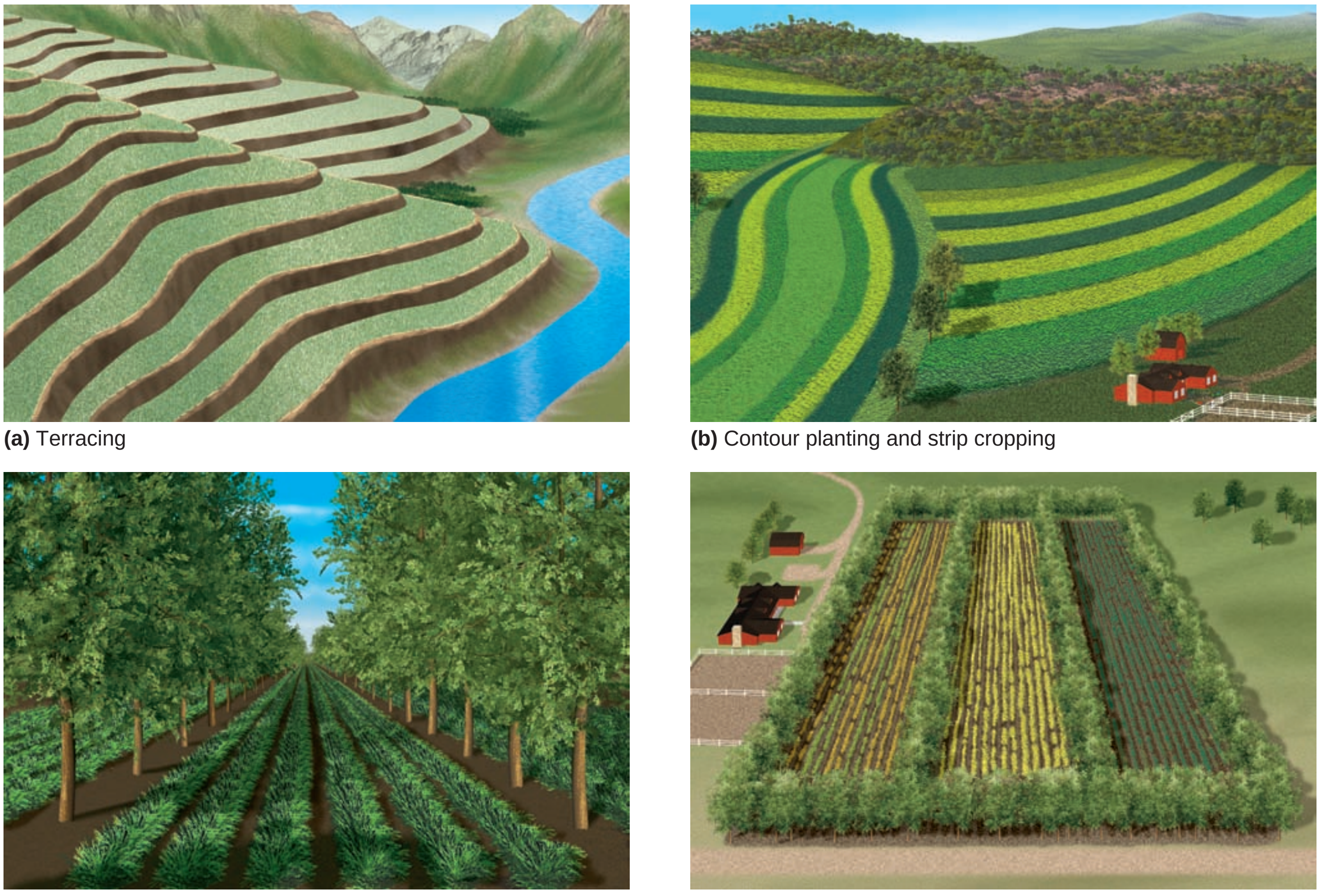
Alley cropping, or *agroforestry* (Figure 10-19c), is yet another way to slow erosion. One or more crops are planted together in strips or alleys between trees and shrubs, which provide shade. This reduces water loss by evaporation and helps retain and slowly release soil moisture—an insurance policy during prolonged drought. The trees also can provide fruit, fuelwood, and trimmings that can be used as mulch (green manure) for the crops and as feed for livestock.

Farmers can establish *windbreaks*, or *shelterbelts*, of trees around crop fields to reduce wind erosion (Figure 10-19d). The trees retain soil moisture, supply wood for fuel, increase crop productivity by 5–10%, and provide habitats for birds and for insects that help with pest control and pollination.

Eliminating the plowing and tilling of soil greatly reduces soil erosion. Many farmers in the United States and several other countries practice *conservation-tillage farming* by using special tillers and planting machines that drill seeds directly through crop residues into the undisturbed soil. The only soil disturbance is a narrow slit and weeds are controlled with herbicides. Such *no-till* and *minimum-tillage* farming also increases crop yields; reduces the projected threat of climate change by storing more carbon in the soil; reduces water pollution from sediment and fertilizer runoff; and lowers use of water, pesticides, and tractor fuel.

GOOD NEWS

In 2008, farmers used conservation tillage on about 41% of U.S. cropland. The USDA estimates that using conservation tillage on 80% of U.S. cropland would reduce soil erosion by at least half. No-till cultivation is



(a) Terracing

(b) Contour planting and strip cropping

(c) Alley cropping

(d) Windbreaks

Figure 10-19 Soil conservation methods include **(a)** terracing, **(b)** contour planting and strip cropping, **(c)** alley cropping, and **(d)** windbreaks (**Concept 10-6**). The problem is that modern industrialized farming operations make little use of these well-known and effective ways to conserve fertile topsoil.

used on less than 7% of the world's cropland, although it is widely used in some countries, including the United States, Brazil, Argentina, Canada, and Australia. But conservation tillage is not a cure-all. It requires costly machinery and works better in some soils than in others. It is not useful for wetland rice and root crops such as potatoes, and it can result in increased use of herbicides.

An additional way to conserve the earth's topsoil is to retire the estimated one-tenth of the world's marginal cropland that is highly erodible and accounts for the majority of the world's soil erosion. The goal would be to identify *erosion hotspots*, withdraw these areas from cultivation, and plant them with grasses or trees, at least until their soils have been renewed.

■ **CASE STUDY**

Soil Erosion in the United States

Americans learned a harsh environmental lesson in the 1930s, when much of the topsoil in several dry and windy midwestern states was lost because of a combination of poor cultivation practices and prolonged drought. In 1935, prompted by the loss of soil, farms, and jobs in this "dust bowl," the United States passed the *Soil Erosion Act*, which established the Soil Conservation Service (SCS) as part of the USDA. Soil conservation districts were formed throughout the country, and farmers and ranchers were given technical assistance to set up soil conservation programs. (The SCS is now called the Natural Resources Conservation Service, or NRCS.)

Despite such efforts, a third of the country's original topsoil is gone and much of the rest is degraded. In the state of Iowa, which has the world's highest concentration of prime farmland, half of the topsoil is gone after a century of farming. According to the NRCS, 90% of American farmland is, on average, losing topsoil 17 times faster than new topsoil is being formed.

Of the world's major food-producing nations, only the United States is sharply reducing some of its soil losses through a combination of conservation-tillage farming and government-sponsored soil conservation programs. Under the 1985 Food Security Act (Farm Act), more than 400,000 farmers participating in the Conservation Reserve Program received subsidy payments for taking highly erodible land—totaling an area larger than the U.S. state of New York—out of production and replanting it with grass or trees for 10–15 years. Since 1985, these efforts have cut soil

GOOD NEWS

losses on U.S. cropland by 40%. However, effective soil conservation is practiced today on only half of all U.S. agricultural land.

CONNECTIONS

Corn, Ethanol, and Soil Conservation

In recent years, some U.S. farmers have been taking erodible land out of the conservation reserve in order to receive generous government subsidies for planting corn (which removes nitrogen from the soil) to make ethanol for use as a motor vehicle fuel. This has led to mounting political pressure to abandon or sharply cut back the highly successful soil conservation reserve program.

Restore Soil Fertility

Soil conservation is the best way to maintain soil fertility. The next best option is to restore some of the lost plant nutrients. To do this, farmers can use **organic fertilizer** from plant and animal materials or **commercial inorganic fertilizer** produced from various minerals.

There are several types of *organic fertilizers*. One is **animal manure:** the dung and urine of cattle, horses, poultry, and other farm animals. It adds organic nitrogen and stimulates the growth of beneficial soil bacteria and fungi. Another type, called **green manure**, consists of freshly cut or growing green vegetation that is plowed into the topsoil to increase the organic matter and humus available to the next crop. A third type is **compost**, produced when microorganisms in soil break down organic matter such as leaves, crop residues, food wastes, paper, and wood in the presence of oxygen. Organic agriculture (**Core Case Study**) uses only these types of fertilizers.

Crops such as corn and cotton can deplete nutrients in the topsoil (especially nitrogen) if they are planted on the same land several years in a row. *Crop rotation* provides one way to reduce these losses. Farmers plant areas or strips with nutrient-depleting crops one year. The next year, they plant the same areas with legumes, whose root nodules add nitrogen to the soil. This not only helps to restore soil nutrients but also reduces erosion by keeping the topsoil covered with vegetation.

The active ingredients in *commercial inorganic fertilizers* used by many farmers (especially in developed countries) are inorganic compounds that contain *nitrogen*, *phosphorus*, and *potassium*. Other plant nutrients may be present in low or trace amounts. Inorganic fertilizer use has grown more than eleven-fold since 1950, and it now accounts for about one-fourth of the world's crop yield. Without careful control, these fertilizers can run off the land and pollute nearby bodies of water and coastal estuaries where rivers empty into the sea (see Connections, p. 220). These fertilizers can help to replace depleted inorganic nutrients, but they do not replace organic matter.

Reduce Soil Salinization and Desertification

We know how to prevent and deal with soil salinization, as summarized in Figure 10-20.

We cannot control the timing and location of prolonged droughts caused by natural factors. But we can reduce population growth, overgrazing, deforestation, and destructive forms of planting, irrigation, and mining, which have left much land vulnerable to soil erosion and thus desertification. We can also work to decrease the human contribution to projected climate change, which is expected to increase severe and prolonged droughts in larger areas of the world during this century. It is possible to restore land suffering from desertification by planting trees (Chapter 9 Core Case

Figure 10-20 Methods for preventing and cleaning up soil salinization (**Concept 10-6**). **Questions**: Which two of these solutions do you think are the most important? Why?

Study, p. 178) and grasses that anchor topsoil and hold water. Other remedies are to establish windbreaks (Figure 10-19d) and to grow trees and crops together (Figure 10-19c).

Practice More Sustainable Aquaculture

Figure 10-21 lists some ways to make aquaculture more sustainable and to reduce its harmful environmental effects. Open-ocean aquaculture, which the United States is planning to develop, is one such alternative. It involves raising large carnivorous fish in underwater pens located up to 300 kilometers (190 miles) offshore (Figure 9-23, p. 201). The fish are fattened with fish meal supplied by automated buoys and wastes are diluted in the open ocean.

Using another approach, scientists are reducing damage to coastal areas in Florida by raising shrimp far inland in zero-discharge freshwater ponds. **GREEN CAREER:** Sustainable aquaculture

However, making aquaculture more sustainable will require some fundamental changes. One such change would be for more consumers to choose fish species that feed on plants rather than on other fish. Raising carnivorous fishes such as salmon, trout, tuna, grouper, and cod contributes to overfishing of species used to feed these carnivores, and it will eventually be unsustainable. For example, it takes an average of 2 kilograms (4.4 pounds) of wild fish to produce 1 kilogram (2.2 pounds) of the 10 most commonly farmed fish species. Raising plant-eating fishes such as carp and tilapia (called the chicken of fish farming) does not add to this problem and is a more sustainable form of aquaculture.

Another such change would be for fish farmers to emphasize *polyaquaculture*, which has been part of aquaculture for centuries, especially in Southeast Asia. Polyaquaculture operations raise fish or shrimp along with algae, seaweeds, and shellfish in coastal lagoons, ponds, and tanks. The wastes of the fish or shrimp feed the other species, and in the best of these operations, there are just enough wastes from the first group to feed the second group. This applies the recycling and biodiversity **principles of sustainability**.

Produce Meat More Efficiently and Eat Less Meat

Meat production and consumption account for the largest contribution to the ecological footprints of most individuals in affluent nations (**Concept 1-2**, p. 9). If everyone in the world today was on the average U.S. meat-based diet, the current annual global grain harvest could sustainably feed only about one-third of the world's current population.

A more sustainable form of meat production and consumption involves shifting from less grain-efficient forms of animal protein, such as beef, pork, and carnivorous fish produced by aquaculture, to more grain-efficient forms, such as poultry and herbivorous farmed fish (Figure 10-22), as many people are doing. Other people are simply eating less meat, some of them by having one or two meatless days per week. This reduces their ecological footprints, and many doctors argue that it also improves their health and increases their life expectancies. According to Dr. Rajendra Pachauri, head of the U.N. Intergovernmental Panel on Climate Change, eating less meat, especially less red meat, is the single best way to reduce one's contribution to projected climate change.

Some people are going further and eliminating most or all meat from their diet. They are replacing it with a vegetarian diet that includes a healthy combination

Solutions

More Sustainable Aquaculture

- Restrict locations of fish farms to reduce losses of mangrove forests and estuaries
- Improve management of aquaculture wastes
- Reduce escape of aquaculture species into the wild
- Raise some aquaculture species in deeply submerged cages to protect them from wave action and predators and to allow dilution of wastes into the ocean
- Certify sustainable forms of aquaculture and label products accordingly

Figure 10-21 Ways to make aquaculture more sustainable and to reduce its harmful effects. **Questions**: Which two of these solutions do you think are the most important? Why?

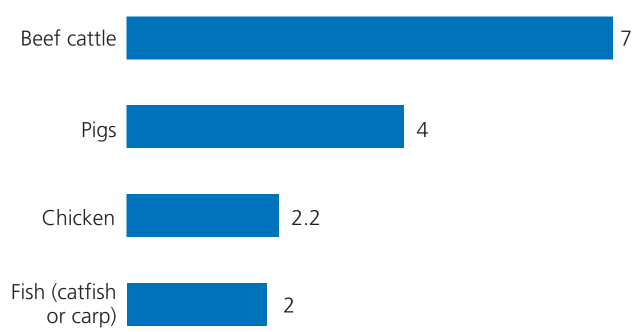


Figure 10-22 Efficiency of converting grain into animal protein. (Data in kilograms of grain per kilogram of body weight added.) **Question**: If you eat meat, what changes could you make in your meat-eating habits to reduce your environmental impact? (Data from U.S. Department of Agriculture)

of organically grown fruits and vegetables (**Core Case Study**) and protein-rich foods such as legumes. Some people like to supplement such a diet with moderate amounts of fish.

THINKING ABOUT
Meat Consumption

Would you be willing to live lower on the food chain (**Concept 3-3**, p. 45) by eating little or no meat? Explain.

Shift to More Sustainable Agriculture

Industrialized agriculture produces large amounts of food at reasonable prices. But to a growing number of analysts, this form of agriculture is unsustainable, because it violates the three **principles of sustainability**. It relies more on fossil fuels than on naturally available sunlight; reduces biodiversity and agrobiodiversity; and does not emphasize conservation and recycling of nutrients in topsoil—the irreplaceable base of all food production on land. These facts are hidden from consumers because the harmful environmental costs of food production (Figure 10-7) are not included in the market prices of food.

Figure 10-23 lists the major components of more sustainable agriculture (**Concept 10-6**). One component is *organic farming* (**Core Case Study**). In 2002, agricultural scientists Paul Mader and David Dubois reported the results of a 22-year study comparing organic and conventional farming at the Rodale Institute in Kutztown, Pennsylvania (USA). Figure 10-24 summarizes their conclusions, along with those from a 2005 evaluation of the study by David Pimentel and other researchers.

According to these studies, yields of organic crops in developed countries can be as much as 20% lower than yields of conventionally raised crops. But organic farmers often make up for this difference by not having to use or pay for expensive pesticides, herbicides, and synthetic fertilizers, and usually by getting higher prices for their crops. And a recent review of 286 systems employing organic agriculture in 57 developing countries found that their average yield was 70% higher than that from conventional agriculture.

Organic agriculture is an important start, but will be sustainable only if it puts primary emphasis on conserving the topsoil that supports all crop growth. Another important component of more sustainable agriculture is to rely more on *organic polyculture*—in which a diversity of organic crops are grown on the same plot—than on conventional single-crop organic agriculture. Another form of polyculture is to raise a diversity of animals on the same land.

Of particular interest to some scientists is the idea of growing *perennial crops*—crops that grow back year after year on their own—using polyculture (Science Focus, at right).

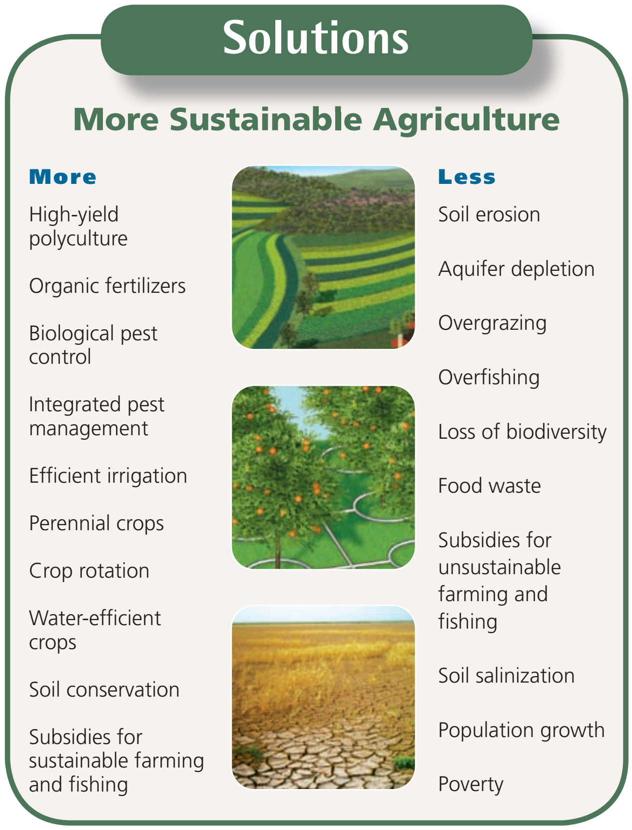


Figure 10-23 Major components of more sustainable, low-throughput agriculture based mostly on mimicking and working with nature (**Concept 10-6**). **Questions**: Which two solutions do you think are the most important? Why?

Well-designed polyculture helps to conserve and replenish topsoil, requires less water, and reduces the need for fertilizers and pesticides. Organic agriculture has the same advantages, plus it decreases the air and water pollution and does not create huge piles of animal wastes associated with conventional industrialized agriculture.

RESEARCH FRONTIER

Organic polyculture. See **www.cengage.com/biology/miller**.

Another key to more sustainable agriculture is to shift from using imported fossil fuel to relying more on solar energy for food production—an important application of the solar energy **principle of sustainability**. Farmers can also use wind, flowing water, and natural gas (produced from farm wastes in *biogas digesters*) to produce electricity and other forms of power needed for food production. And some farmers make money by selling any excess electricity they generate to power companies.

Solutions

Organic Farming

- Improves soil fertility
- Reduces soil erosion
- Retains more water in soil during drought years
- Uses about 30% less energy per unit of yield
- Lowers CO_2 emissions
- Reduces water pollution by recycling livestock wastes
- Eliminates pollution from pesticides
- Increases biodiversity above and below ground
- Benefits wildlife such as birds and bats

Figure 10-24 Environmental benefits of organic farming over conventional farming, based on 22 years of research comparing these two systems at the Rodale Institute in Kutztown, Pennsylvania (USA). (Data from Paul Mader, David Dubois, and David Pimentel)

Some say that making a shift to more sustainable agriculture by using strategies such as those listed in Figure 10-23 is idealistic and cannot work. Proponents disagree. They point out that we have all of the components needed for making such a shift. Some argue that over the next five decades, a combination of education and economic policies that reward more sustainable agriculture can lead to such a shift.

Some analysts contend that three factors have resulted in the current unsustainable systems: (1) our lack of knowledge about sustainability; (2) our failure to include the harmful environmental costs of food production in the market prices of food; and (3) our use of economic systems that reward unsustainable agriculture. These experts argue that if we can find the political and ethical will, we can make the shift to more sustainable ways of producing food.

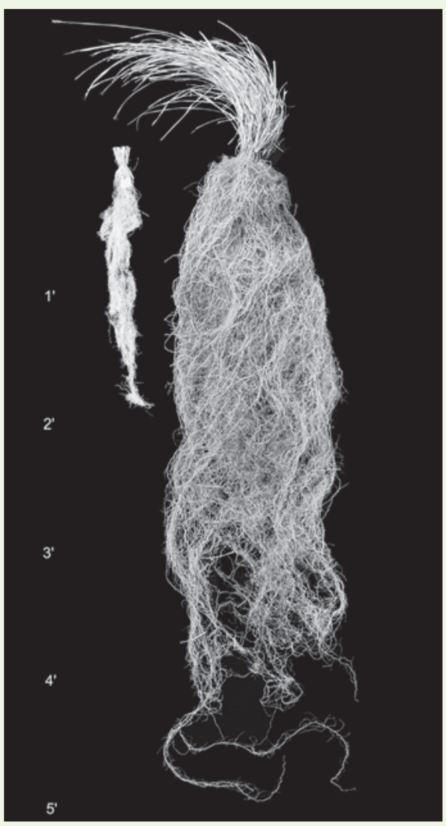
SCIENCE FOCUS

The Land Institute and Perennial Polyculture

Some scientists call for greater reliance on polycultures of perennial crops as a component of more sustainable agriculture. Such crops can live for many years without having to be replanted and are better adapted to regional soil and climate conditions than most annual crops.

Over 3 decades ago, plant geneticist Wes Jackson co-founded The Land Institute in the U.S. state of Kansas. One of the institute's goals has been to use an ecological approach to agriculture. It has copied nature by growing a diverse mixture (polyculture) of edible perennial plants, especially perennial versions of annual grain crops such as wheat, sorghum, and sunflowers.

Because the plants are perennials, there is no need to till the soil and replant seeds each year. This reduces soil erosion and water pollution from eroded sediment, because the unplowed soil is not exposed to wind and rain. And it reduces the need for irrigation because the deep roots of such perennials retain more water than do the shorter roots of annuals (Figure 10-C). Also, there is little or no need for chemical fertilizers and pesticides, and thus little or no pollution from these sources.



Scott Bontz/The Land Institute

Figure 10-C Comparison of the roots of an annual wheat crop plant (left) with the roots of a tallgrass prairie perennial plant, big bluestem (right). The perennial plant is in the ground year-round and is much better at using water and nutrients and making and maintaining healthy soil. It also needs less fertilizer.

Wes Jackson calls for governments to promote this and other forms of more sustainable agriculture that would help to protect soil from erosion, sustain nitrogen nutrients in topsoil, cut the wasteful use of irrigation water, reduce dependence on fossil fuels, eliminate toxins in soil and water, and reduce dead zones in coastal areas caused by excessive runoff of plant nutrients into rivers. He reminds us that "if our agriculture is not sustainable, then our food supply is not sustainable."

Critical Thinking

Why do you think most conventional seed companies are strongly opposed to greatly increased use of perennial polyculture?

Critics say that this approach will not produce enough food and will lead to food shortages. Not so. Experience and research show that well-designed forms of more sustainable polyculture can produce much higher crop yields per unit of land than conventional monocultural agriculture can. Shifting to such agriculture could increase the world's food supply by up to 50%, according to a recent study by University of Michigan scientists.

Analysts suggest six major strategies to help farmers and consumers make the transition to more sustainable agriculture over the next 50 years (**Concept 10-6**). *First*, greatly increase research on sustainable organic farming (**Core Case Study**) and perennial polyculture (Science Focus, p. 233) and on improving human nutrition. *Second*, set up demonstration projects so that farmers can see how more sustainable agricultural systems work. *Third*, set up an international fund to give farmers in poor countries access to forms of more sustainable agriculture. *Fourth*, establish training programs in sustainable agriculture for farmers and government agricultural officials, and encourage the creation of college curricula in sustainable agriculture. *Fifth*, replace government subsidies for environmentally harmful forms of industrialized agriculture with subsidies that encourage more sustainable agriculture. *Sixth*, mount a massive program to educate consumers about the true costs of the food they buy. This would help consumers understand why the current system is unsustainable, and it would build political support for including the harmful costs of food production in the market prices of food.

Consumers Can Buy Local, Grow Some of Their Own Food, and Cut Food Waste

Figure 10-25 lists ways in which you can promote more sustainable agriculture.

What Can You Do?

Sustainable Organic Agriculture

- Waste less food
- Eat less meat or no meat
- Use organic farming to grow some of your food
- Buy organic food
- Eat locally grown food
- Compost food wastes

Figure 10-25 Individuals matter: ways to promote more sustainable agriculture (**Concept 10-6**). **Questions**: Which three of these actions do you think are the most important? Why?

One important component of more sustainable agriculture, according to most experts, will be to have much more of our food grown locally, or at least regionally. Consumers can help farmers to make a transition to more sustainable farming by increasing their demand for organic foods. They can also buy more of their food from local and regional producers in farmers' markets or other outlets. A growing number of people are participating in *community-supported agriculture (CSA)* programs in which they buy shares of a local farmer's crop and receive a box of fruits and vegetables each week during the summer and fall. One commentator referred to this commitment to buying local as "becoming a locavore."

Buying locally supports local economies and farm families, and it might help to slow the rapid conversion of farmland to suburban development, with resulting problems of urban sprawl (p. 109). It can also reduce the environmental impact of most food production, because locally grown food does not have to be transported very far from producer to consumer.

People living in urban areas could grow more of their own food. According to the U.S. Department of Agriculture, around 15% of the world's food is grown in urban areas, and this percentage could easily be doubled. People plant gardens in suburban backyards. In cities, they grow food in vacant lots, on rooftops, in window boxes, and in raised beds in unused or partially used parking lots (a growing practice known as *asphalt gardening*). In London, England, and in the United States, a growing number of city dwellers are raising chickens in their backyard, with the wastes used as fertilizer for backyard gardens.

Shifting to more sustainable agriculture and supplying more food locally could result in more small farms. This means that more people would be making a living by producing food more sustainably for people living in their regions. Eco-farming could be one of this century's challenging new careers for many young people. **GREEN CAREER:** Small-scale sustainable agriculture

Finally, people can sharply cut food waste. This is an important component of improving food security (**Concept 10-5**). In 2008, environmental scientist Vaclav Smil estimated that Americans waste 35-45% of their food supply. This wasted food is worth at least $43 billion a year, almost twice as much as the $24 billion needed to eliminate undernutrition and malnutrition in the world according to U.N. estimates. Many developed countries have similarly high rates of food waste.

We are at a fork in the road. We can keep on using our current food production system, which some experts argue is unsustainable and could collapse if the prices of oil and natural gas rise sharply, as is projected by many economists. Or we can try a new, more sustainable path.

Proponents of decentralizing and diversifying our food production systems say that this major shift will improve local and regional economies by providing large numbers of green jobs. They argue that it will also improve economic and military security for

many nations by reducing their dependence on increasingly expensive imported oil and food. And this shift will sharply reduce the harmful environmental impacts of industrialized agriculture.

Here are this chapter's *three big ideas:*

- About 925 million people have health problems because they do not get enough to eat and 1.6 billion people face health problems from eating too much.
- Modern industrialized agriculture has a greater harmful impact on the environment than any other human activity.
- More sustainable forms of food production will greatly reduce the harmful environmental impacts of current systems while increasing food security and national security for all countries.

REVISITING Organic Agriculture and Sustainability

CORE CASE STUDY

SUSTAINABILITY

This chapter began with a look at how food can be produced by organic agriculture, a rapidly growing component of more sustainable agriculture (**Core Case Study**). Putting more emphasis on diverse organic farming and perennial polyculture could help to reduce the enormous harmful environmental impacts of agriculture as a whole (Figure 10-7).

Making the transition to more sustainable agriculture involves applying the three **principles of sustainability** (see back cover). All of these principles are violated by modern industrialized agriculture, because it depends heavily on nonrenewable fossil fuels, includes too little recycling of crop and animal wastes, accelerates soil erosion, does too little to preserve agrobiodiversity, and can destroy or degrade wildlife habitats and disrupt natural species interactions that help to control pest population sizes. Conventional aquaculture and other forms of industrialized food production violate the principles of sustainability in similar ways.

Thus, making this transition means relying more on solar and other forms of renewable energy and less on fossil fuels. It also means sustaining nutrient cycling through soil conservation and by returning crop residues and animal wastes to the soil. It involves helping to sustain natural and agricultural biodiversity by relying on a greater variety of crop and animal strains. Controlling pest populations through broader use of conventional and perennial polyculture and integrated pest management will also help to sustain biodiversity.

Such efforts will be enhanced if we can control the growth of the human population and our wasteful use of food, water, and other resources. We can also insist that elected officials replace environmentally harmful agricultural subsides and tax breaks with more environmentally beneficial ones and work to include the harmful environmental costs of food production in the market prices of food.

Making the transition to more sustainable forms of food production will not be easy. But it can be done if we heed the ecological lessons from nature represented by the three **principles of sustainability**.

While there are alternatives to oil, there are no alternatives to food.

MICHAEL POLLAN

REVIEW

1. Review the Key Questions and Concepts for this chapter on p. 207. Compare the main components of **organic agriculture** with those of conventional industrialized agriculture.
2. Define **food security** and **food insecurity**. What is the root cause of food insecurity? Distinguish between **chronic undernutrition** (**hunger**) and **chronic malnutrition** and describe their harmful effects. Describe the effects of diet deficiencies in vitamin A, iron, and iodine. What is **overnutrition**, and what are its harmful health effects?
3. What three systems supply most of the world's food? Distinguish among **industrialized agriculture** (**high-input agriculture**), **plantation agriculture**, **traditional subsistence agriculture**, **traditional intensive agriculture**, and **polyculture**. Define **soil** and describe its formation and the major layers in mature soils and why soil conservation is so important. What is a **green revolution**? Describe industrialized food production in the United States and in Brazil.
4. Distinguish between producing crops through *crossbreeding* and producing crops through *genetic engineering*. Describe

industrialized meat production. What is a **fishery**? What is **aquaculture**?

5. What are the major harmful environmental impacts of agriculture? What is **soil erosion** and what are its two major harmful environmental effects? What is **desertification** and what are its harmful environmental effects? Distinguish between **salinization** and **waterlogging** of soil and describe their harmful environmental effects.

6. What factors can limit green revolutions? Describe the use of energy in industrialized agriculture. Describe the advantages and disadvantages of genetically engineered foods. Explain how most industrialized food production systems reduce biodiversity and agrobiodiversity. Describe the advantages and disadvantages of industrialized meat production. Describe the advantages and disadvantages of aquaculture.

7. What is a **pest**? Define and give two examples of a **pesticide**. Describe Rachel Carson's contribution to environmental science. Describe the advantages and disadvantages of modern pesticides. Describe the use of laws to help protect us from the harmful effects of pesticides. Describe seven alternatives to conventional pesticides. Define **integrated pest management** (**IPM**) and discuss its advantages.

8. Describe three ways in which governments influence food production. List six ways to reduce nutrition-related premature childhood deaths. What is **soil conservation**? Describe soil erosion and soil conservation in the United States. Describe seven ways to reduce soil erosion. Distinguish among the use of **organic fertilizer**, **commercial inorganic fertilizer**, **animal manure**, **green manure**, **compost**, and *crop rotation* as ways to help restore soil fertility. Describe ways to prevent and clean up *soil salinization* and *desertification*.

9. Describe ways to produce meat more efficiently and sustainably. Describe ways to make aquaculture more sustainable. What are three factors that contributed to the growth of the current industrialized food production systems? What are the major components of *more sustainable agriculture*? What are the major advantages of *organic agriculture*? Describe the advantages of relying more on polycultures of perennial crops. What can individuals do to promote more sustainable agriculture?

10. What are this chapter's *three big ideas*? Describe the relationships among organic agriculture (**Core Case Study**), more sustainable food production, and the three **principles of sustainability**.

CORE CASE STUDY

SUSTAINABILITY

Note: Key terms are in **bold** type.

CRITICAL THINKING

1. Do you think that the advantages of organic agriculture (**Core Case Study**) outweigh its disadvantages? Explain. Do you eat or grow organic foods? If so, explain your reasoning for making this choice. If not, explain your reasoning for the food choices you do make.

CORE CASE STUDY

2. What are the three most important actions you would take to reduce chronic hunger and malnutrition **(a)** in the country where you live and **(b)** in the world?

3. Explain why you support or oppose greatly increased use of **(a)** genetically modified food **(b)** polyculture, and **(c)** perennial polyculture.

4. Suppose you live near a coastal area and a company wants to use a fairly large area of coastal marshland for an aquaculture operation. If you were an elected local official, would you support or oppose such a project? Explain. What safeguards or regulations would you impose on the operation?

5. Explain how widespread use of a pesticide can **(a)** increase the damage done by a particular pest and **(b)** create new pest organisms.

6. If increased mosquito populations threatened you with malaria or West Nile virus, would you want to spray DDT in your yard and inside your home to reduce the risk? Explain. What are the alternatives?

7. List three ways in which your lifestyle directly or indirectly contributes to soil erosion.

8. According to physicist and philosopher Albert Einstein, "Nothing will benefit human health and increase chances of survival of life on Earth as much as the evolution to a vegetarian diet." Do you agree with this statement? Explain. Are you willing to eat less meat or no meat? Explain.

9. Congratulations! You are in charge of the world. List the three most important features of your **(a)** agricultural policy, **(b)** strategy for reducing soil erosion, **(c)** strategy for more sustainable harvesting and farming of fish and shellfish, and **(d)** global pest management strategy.

10. List two questions that you would like to have answered as a result of reading this chapter.

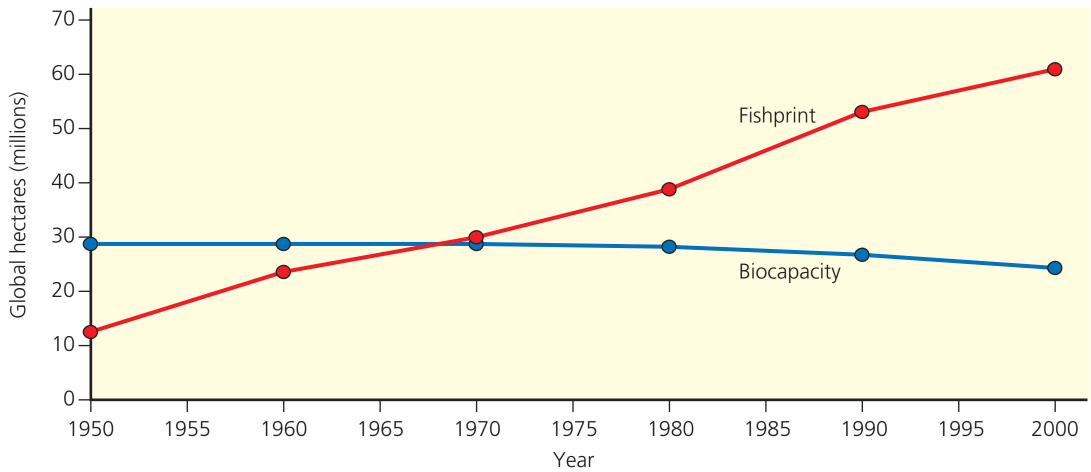
ECOLOGICAL FOOTPRINT ANALYSIS

A *fishprint* provides a measure of a country's fish harvest in terms of area. The unit of area used in *fishprint analysis* is the global hectare (gha), a unit weighted to reflect the relative ecological productivity of the area fished. When compared with the fishing area's *biocapacity*, its ability to provide a stable supply of fish year after year, again in terms of area, it indicates whether the country's fishing intensity is sustainable. The fishprint and biocapacity are calculated using the following formulas:

$$\text{Fishprint in (gha)} = \frac{\text{metric tons of fish harvested per year}}{\text{productivity in metric tons per hectare}} \times \text{weighting factor}$$

$$\text{Biocapacity in (gha)} = \frac{\text{sustained yield of fish in metric tons per year}}{\text{productivity in metric tons per hectare}} \times \text{weighting factor}$$

The following graph shows the earth's total fishprint and biocapacity. Study it and answer the following questions.



1. Based on the graph
   a. What is the current status of the global fisheries with respect to sustainability?
   b. In what year did the global fishprint begin exceeding the biocapacity of the world's oceans?
   c. By how much did the global fishprint exceed the biocapacity of the world's oceans in 2000?
2. Assume a country harvests 18 million metric tons of fish annually from an ocean area with an average productivity of 1.3 metric tons per hectare and a weighting factor of 2.68. What is the annual fishprint of that country?
3. If biologists determine that this country's sustained yield of fish is 17 million metric tons per year
   a. What is the country's sustainable biocapacity?
   b. Is the county's fishing intensity sustainable?
   c. To what extent, as a percentage, is the country under- or overshooting its biocapacity?

LEARNING ONLINE

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